Vol. VI
No. 5

Monograph Supplements

March, 1905
Whole No. 28

THE

Psychological Review

EDITED BY

J. MARK BALDWIN
JOHNS HOPKINS UNIVERSITY

HOWARD C. WARREN
PRINCETON UNIVERSITY

AND

CHARLES H. JUDD
YALE UNIVERSITY
(*Editor of the Monograph Series*)

University of Iowa Studies in Psychology

No. IV

EDITED BY

CARL EMIL SEASHORE
Professor of Psychology in the State University of Iowa, Iowa City, Iowa

THE MACMILLAN COMPANY,
41 NORTH QUEEN ST., LANCASTER, PA.
66 FIFTH AVENUE, NEW YORK.
AGENT: G. E. STECHERT, LONDON (2 Star Yard, Carey St. W. C.);
LEIPZIG (Hospital St., 10; PARIS (76 rue de Rennes).

PERIMETRY OF THE LOCALIZATION OF SOUND.

BY DANIEL STARCH, A.M.

The purpose of this research is, first, to determine the data and elementary processes of the localization of sound; and second, to obtain some accurate measurements of the ability to discriminate between directions of sounds.

The localization of sound, as a field for investigation, was opened by Weber[1] in 1848, and since then various problems have been approached with more or less success. The early experimental contributions were crude and introductory, and only the more recent researches were made along specific lines, such as peculiarities of median plane localization, the outer ear in its relation to the localization of sound, the localization of fused sounds, etc. The keenness of perception of direction has been tested in part but the results thus far gained disagree in their essential respects, demanding more detailed consideration.

In the present investigation, typical directions in two representative series of planes (horizontal and vertical) were chosen. Accordingly, two main series of experiments were undertaken. The aim of the first was to find the least perceptible difference between directions in horizontal planes, and the aim of the second was to find the least perceptible difference between directions in vertical planes.

The apparatus consisted of the Seashore sound perimeter which was described by the designer in THE PSYCHOLOGICAL REVIEW, X., pp. 64–68. Professor Seashore has kindly consented to reprint the description in this connection.

THE SOUND PERIMETER.

Recent studies in auditory space perception have shown that the power to localize sounds rests, to a great extent, upon secondary factors. What unaided introspection would lead us to consider direct acoustic sensory data, exact experiment often reveals to be only associations or the result of subconscious

[1] *Berichte der kgl. sächs. Ges. der. Wiss.*, II., Bd. (1848), S. 237.

influences of some sort. In future experiments more attention must be paid to the elimination or control of these associations and suggestions. Within the last few years, much good work has been done in the study of the localization of sound, but all with crude and often inadequate apparatus. None of the sound cages, or substitutes for the same, which have been used, could have been operated without giving suggestions that would tend to invalidate the results. Only those who, like the writer, have been engaged in these experiments, can fully appreciate this criticism. Results have been obtained at the expense of wasted time and patience in the effort to conduct the experiments on such plans that the shortcomings of the apparatus might be overcone.

In order to be adequate for most purposes, the apparatus for the producing and registering of the sound which is to be located should permit, among others, the following variations in the stimulus without giving any suggestion or counter-suggestion to the observer: (1) the direction of the stimuli from the middle of the aural axis, (2) the intensity of each of the stimuli, (3) the distance of one stimulus, (4) the number of stimuli to be given simultaneously or in succession, and (5) the order and frequency of stimuli from a given position.

The sound perimeter shown in Fig. 1, has been designed to meet these requirements. It consists of a system of telephone receivers so mounted and connected as to make the above-named variations possible. The main frame is made of iron tubing and braced in such a way as to afford the maximum rigidity with a minimum of material which might reflect sound. The receivers through which the stimuli are produced, are mounted on movable arms, which may be denoted *A*, *B*, *C*, and *D*, respectively. Arms *A* and *B*, each representing an arc of 135° of a circle whose radius is one meter, are so mounted on a common center at the top that they may swing in the same course, describing a part of the surface of a sphere one meter in radius. Each of these arms carries a pointer, which moves under the circular scale placed above the bearings. This scale is graduated in five degree-units and marked with large figures, which may be read from the experimenter's position behind the tablet on the main support of the frame. The two arms are mounted on a common axis, but they turn on independent bearings, so that there is no friction between them. The arms are turned by means of cords which run from the experimenter's tablet up to pulleys at the top of the frame and thence to wheels mounted on the upward projections of the arms. There are two of these cords for each arm; pulling one cord turns the arm to the left, and pulling the other turns it in the opposite direction.

The third arm, *C*, turns in the surface of the same sphere as the other two arms, but is mounted on the side and counterbalanced, so that it may be turned readily by means of the crank which is seen directly above the tablet. The pointer on the crank runs over a circular scale which is graduated in five-degree units, in the same manner as the scale for arms *A* and *B*. The axle which carries this arm may be drawn back through the frame so that the arm may pass the other two arms without striking at the top, and so as to be out of the way when not in use.

Arm *C* may be removed by pulling the axle out after detaching the crank. and arm *D*, a straight rod, will fit in its place of support. In Fig. 1, arm *D* is seen only in part, being stored away on the side of the main upright of the frame, This arm carries the receiver on one end, and is graduated in centimeters for guidance in the adjustment of the distance of the receiver from the center of the

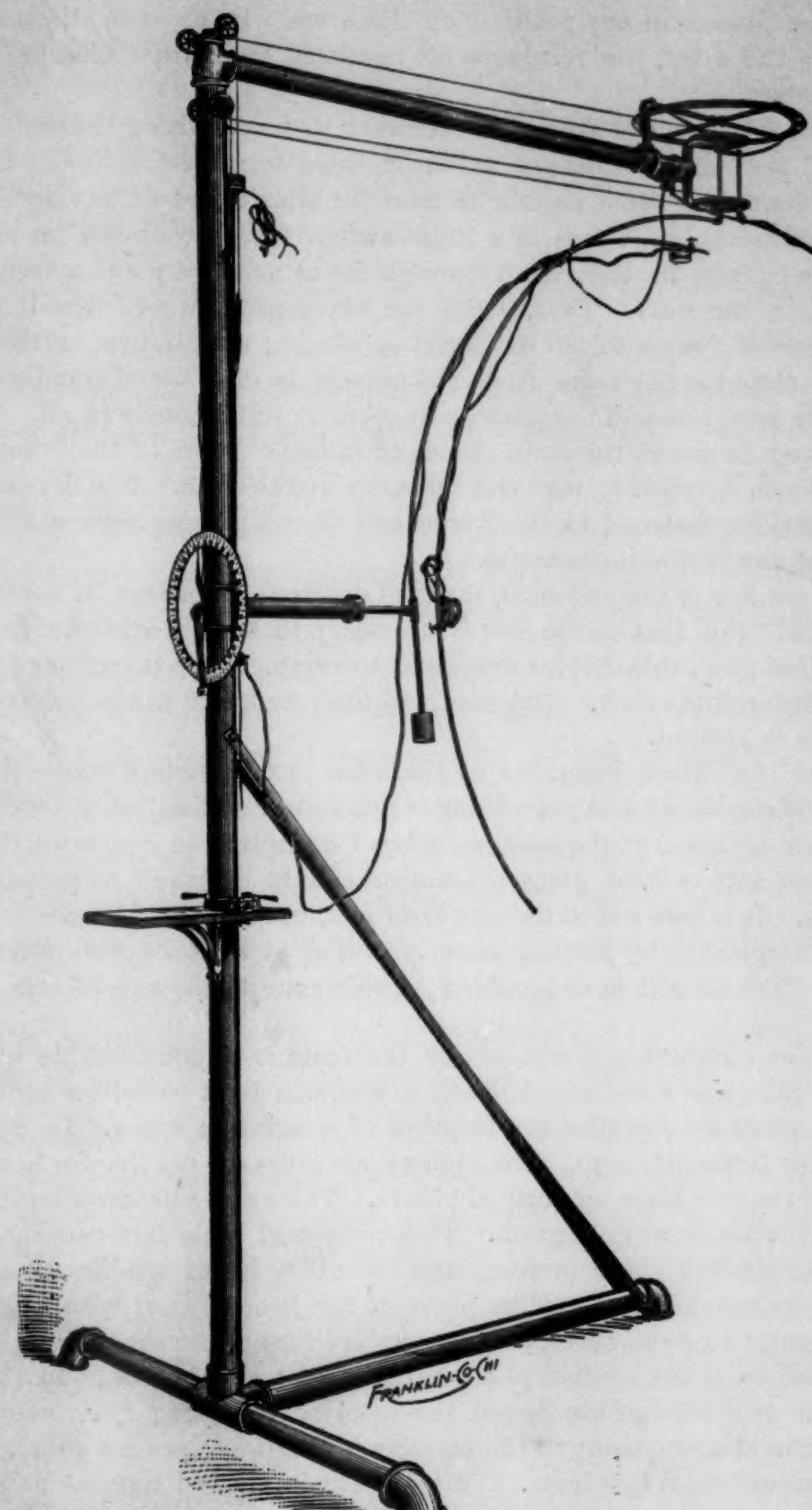


FIG. 1.

sphere. The arm is three meters long and slides freely in the horizontal direction.

For ordinary purposes only one receiver is needed on each arm, but it is evident that any number of receivers desired may be mounted on each arm for the purpose of special experiments. The receivers are clamped by a thumb

screw and may be placed in any position on the arms. In order to eliminate conduction along the arms, the receivers are insulated from their clamps by means of soft rubber.

Soft and flexible wires run from the receivers to terminals on the surface of the frame and permanent wires are laid from these terminals, inside of the frame, to the tablet. The same curcuit is used for arms *C* and *D*, as they are never used simultaneously. There is a knife switch for each circuit on the tablet and all the circuits are completed through the same battery and mercury key (not shown in the cut). Thus, when the key is pressed, a click will be heard in a receiver if the switch in its circuit is closed; and if two or three switches remain closed at the same time, the current is distributed equally to the corresponding receivers and the clicks will occur simultaneously in all.

Resistance may be put in the main circuit or in one or more of the branch circuits, as the needs may be, to vary the intensity of the click. If a dry-battery is used it may be fastened to the frame and then the apparatus will be complete without any further accessories.

To vary the quality of the stimulus, tones of different pitch may be substituted for the click. For that purpose it is necessary to have electric tuning-forks of the desired pitch in a distant room and to complete the perimeter circuit as a shunt through the fork. The tone will then be heard in the receiver whenever the key is pressed.

The center of the sphere described by the arms is 1.73 meters above the floor. A high, adjustable stool is placed under this center and adjusted for the observer so that the center of the observer's head occupies the center of the sphere. If a head rest is used, great precaution should be taken to prevent disturbing effects. It is best not to use any head rest, but to check the position of the observer frequently by putting arms *A* and *B* at opposite points and sighting across. The height is determined by reference to the axis of arm *C* or arm *D*.

The scheme for numbering the points on the scale is of considerable importance. That plan has been adopted which students tend to follow spontaneously when asked to describe the location of a point in space. In this there is no number higher than 90. The upper scale gives the reading for horizontal planes and the side scale for vertical planes. The nomenclature adopted may be described without any diagram. The horizontal scale has two zero-points, one in the median plane in front and the other in the median plane behind; *i. e.*, every point in the median plane of the head is at 0° with reference to the horizontal plane of space, and degrees are counted toward the right and toward the left from the median plane both in front and behind. In the vertical scale, the two zero-points are at the level of the ears; *i, e.*, every point in the horizontal plane through the ears is at 0°, and degrees are counted upward and downward from this level. This gives a simple and natural nomenclature for direction, *e. g.*, a point is 'in front, 15° left and 25° up.' The upper scale may be turned so that this system will correspond to any desired position of the observer.

This apparatus will favor the use of the method of right and wrong cases and the method of minimal changes, in which it is not necessary for the observer to estimate degrees. However, it is sometimes advantageous to allow the observer to indicate the direction with a pointer; the experimenter may then swing the perimeter arms to such a point and read off the result on the scales.

This brief statement, supplemented by the figure, may suffice to give a general idea of the apparatus. Its special merits are, that it enables the experimenter to stand in one place throughout complicated series of experiments and operate all the parts of the apparatus without giving any suggestion by movement or delay, that the movable parts of the apparatus are made to act without sound or jar, and that it makes it possible to vary, measure, and control the essential factors. C. E. SEASHORE.

The perimeter was so located in an almost cubical room (20 ft. × 16 ft. × 13 ft., and containing only the necessary apparatus) that the center of the sphere described by its arms was equidistant from the walls of the room. In order to approximate perfect uniformity in the reflection of the sounds from all directions still further, the sounds were always given on the same side, and instead of swinging the arms of the perimeter to the different standards, the observers turned to the required standard positions. Following the adopted nomenclature of the perimeter, the points used as standards can be most easily located with reference to the accompanying diagram (Fig. 2). This diagram represents the right hemisphere. The letters uf, df, ub, db, rf, lf, rb, and lb stand for up front, down front, up back, down back, right front, left front, right back, and left back, respectively. To describe the position of a point, we mention first its plane and then its location in that plane, as for example, 30° u, 15° rf; or 15° d, 45° rb, etc.

The stimulus was furnished by an electric fork of 100 vibrations, in a distant room, kept vibrating by a current completing its circuit through the receivers of the perimeter. The sound thus heard from the receivers was favorable for localization and of sufficient strength to be heard 12–15 meters away.

The method followed is an abbreviated form of the method of right and wrong cases or 'Konstanzmethode' as Müller[1] prefers to call it. This method was preferred to the method of minimal change mainly because it gives more accurate and precise judgments. The stimuli were the same but were given in different positions with intervening time intervals which kept the mind more alert for minute distinctions than where a continuous stimulus moved along slowly until the observer called halt. In a few preliminary trials the failure of the method of minimal

[1] *Die Gesichtspunkte und die Tatsachen der Psychophysichen Methodik.*

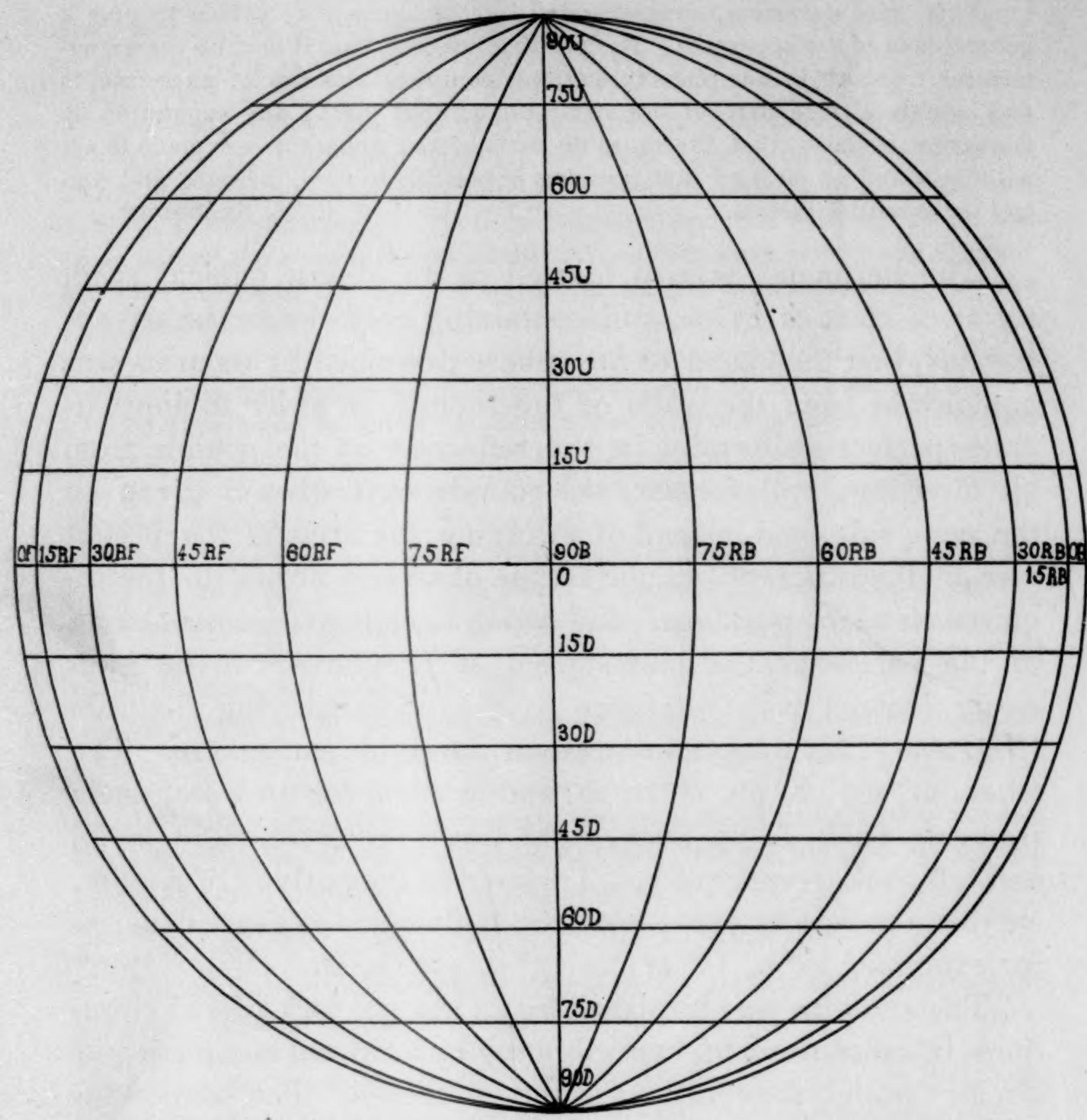


FIG. 2.

change to hold the attention of the observer and to suggest directly the contrast of different directions became evident.

The particular type of the Konstanzmethode that was adopted is the one which allows the observer to have choice between two alternatives only. The equality or doubtful judgment was not permitted. Elimination of that judgment greatly simplifies the computation and final evaluation of the results, and is an incitement to keep the observer aggressive. In the words of Professor Jastrow[1] the equality judgment 'encourages fatigue (weariness) and diminishes the regularity and simplicity of the

[1] 'Critique of Psychophysic Methods,' *Am. Journ. Psych.*, I., p. 283.

judging process.' On the same point Whipple[1] says that the equality judgment induces the tendency 'to pronounce two impressions alike when the difference between them is not clearly made out.'

To illustrate the actual procedure of making the tests, let us suppose that we wish to take the record of the standard 0°f, horizontal plane through the aural axis. The observer is seated on the stool having his eyes closed and his head at the center of the sphere. With the receiver at the standard, 0°f, the experimenter presses the key twice in rapid succession giving two short sounds, each of which has a duration of about one fifth of a second, and the interval is also one fifth of a second. With the other hand he quickly moves the receiver 5° either right or left and there again gives the same double stimulus. The time interval between the two stimuli is about one second. The observer then gives his judgment by saying that the second stimulus is on one side or the other of the first one. If after all the trials with the interval, 5°, have been made, more than 90 per cent. of the judgments are correct, the next smaller interval, 3°, must be tried; or, if less than 60 per cent. are correct, the next larger interval, 10°, must be tried. If that is not sufficient, the interval may be increased 5° each time until the percentage of correct judgments lies within the limits.

The method was thus abbreviated in order to save time in experimentation. This was thought justifiable by the fact that at the beginning of each row of standards that are in the same plane the smallest interval was always tried first and, if that was not sufficient, large intervals were taken successively. The interval that was found satisfactory at a given standard was the one first employed at the following standard. But if this interval was not adequate there, a larger or smaller step was used as the case demanded. Prejudice that would be involved in the arbitrary selection of an interval for a given standard was thus avoided.

In order to have a uniform basis for evaluating the tests on all the standards, the threshold of discrimination for directions was found by the 'table for determining the probable error

[1] 'Discrimination of Clangs and Tones,' *Am. Journ. Psych.*, XII., p. 412.

from the percentage of right cases and amount of difference.[1] On this basis the required interval for each standard was computed to make the per cent. of correct judgments 75.

Sixteen persons who may be divided into two groups took part as observers.[2] The four regular observers, *W*, *K* (women), *B*, and *S* (men), had considerable training in observing and in conducting psychological experiments. *K* and *B* had become familiar with these experiments through the preliminary tests. *W* is an instructor in the University and *K*, *B*, and *S* are graduate students in psychology. Each one gave fifty judgments at each standard. The additional observers who were employed in some special tests, *Wi*, *C* (women), *H*, *Ch*, *Kl*, *Sc*, *G*, *M*, *We*, *Se*, *Bu*, and *Ho* (men), are also students and are in a general way familiar with psychological experiments.

The eyes were not blindfolded (except in one case) but merely closed and no head rest was used to guard against possible disturbing effects from this source. The exact position of the observers was checked by sighting across small labels which were fastened on the walls of the room. In order to distribute the effect of practice, fatigue, etc., the tests of each individual were made in the double fatigue order. The test periods were never longer than an hour and were always at the same time of the day for each person. The experiments were made during the academic year 1903–4.

Series I. Horizontal Planes.

The immediate aim of this series was to measure the power of discrimination between directions of sounds in horizontal planes. The points or standards, ninety two in number, are located in the following planes (see Fig. 2): 0°, 15°u, 15°d, 30°u, 30°d, 45°u, 60°u, and 75°u, of which the last two have seven standards each, 30° apart, while the others have thirteen standards each, 15° apart.

Each of the four regular observers, *W*, *K*, *B*, and *S*, gave fifty judgments at each standard, passing through the entire

[1] Fullerton and Cattell, *On the Perception of Small Differences*, p. 16. (Univ. Penn. Phil. Series, No. 2.)

[2] The writer wishes to express his thanks to the observers.

series of points in the double fatigue order, which gives in all over 18,000 separate judgments.

No extensive tests were made on the left side of the median plane for the reason that some tests made on both sides did not indicate any essential differences between the two sides.

The results are not given in statistics but in the form of curves, which seemed preferable. But to illustrate the statistical form of the records the following section is adduced.

HORIZONTAL PLANE 15°u.

Standards.	0°f	15°rf	30°rf	45°rf	60°rf	75°rf	90°r
Intervals.	D3°	D3°	D3°	D3°	D3°	D3°	D3°
	x	I	I	x	I	x	x
	x	I	I	I	I	I	x
	I	x	I	I	I	I	I
	I	I	x	I	I	I	I
	I	I	I	I	I	x	I
	I	I	I	I	I	I	I
	I	I	I	I	x	I	x
	I	x	I	I	x	x	x
	I	I	I	x	x	x	I
	I	I	x	I	x	I	x
	I	I	I	I	I	I	I
	I	I	I	I	x	I	I
	I	I	I	x	x	x	I
	I	I	I	I	I	I	I
	I	I	I	I	I	x	I
	I	I	I	x	x	I	x
	I	I	I	x	I	I	I
	I	I	I	I	I	x	x
	I	x	I	I	x	x	I
	I	I	x	I	I	I	I
	I	I	I	I	I	I	x
	x	I	x	I	x	x	I
	I	I	I	x	I	I	x
	I	I	I	I	I	I	I
	I	I	I	I	I	x	x
	88%	88%	84%	76%	64%	60%	60%
Interval for 75%	1.7°	1.7°	2.0°	2.9°	5.7°	7.9°	7.9°

The broken lines in the charts represent graphically the accuracy of localization in the horizontal planes for each one of the four observers. The continuous line embodies the average of the four. The composite of the averages in which the details disappear has value only in so far as it is a means of comparison of general features. In these figures the radii represent the standard directions, the distances between the arcs represent degrees and the center of the arcs represents the center of the

observer's head. Thus, if the curve passes through the intersection of the third semicircle with the radius 15°rf, it means that a sound must be 3° right or left of 15°rf to be perceived as coming from a point right or left of the standard. In those places where the curves go beyond the area of the charts the intersections are indicated by the angles which the curves make with the extended radii. It must be noted that a degree does not represent the same actual distance in all the planes. Its value is greatest in the horizontal plane through the aural axis, or equatorial plane, and is less for the others, namely:

In horizontal plane	0°	1° = 17.5 mm.
" " "	15°u (or d)	1° = 16.9 "
" " "	30°u "	1° = 15.2 "
" " "	45°u "	1° = 12.4 "
" " "	60°u "	1° = 8.8 "
" " "	75°u "	1° = 4.5 "

Figs. 4–11 have been reduced on this scale so that 1 mm. of the radial distance is equal to 2.6 mm. of actual distance between two receivers, and these eight figures are on the same absolute scale. Fig. 3 is drawn on a much larger scale.

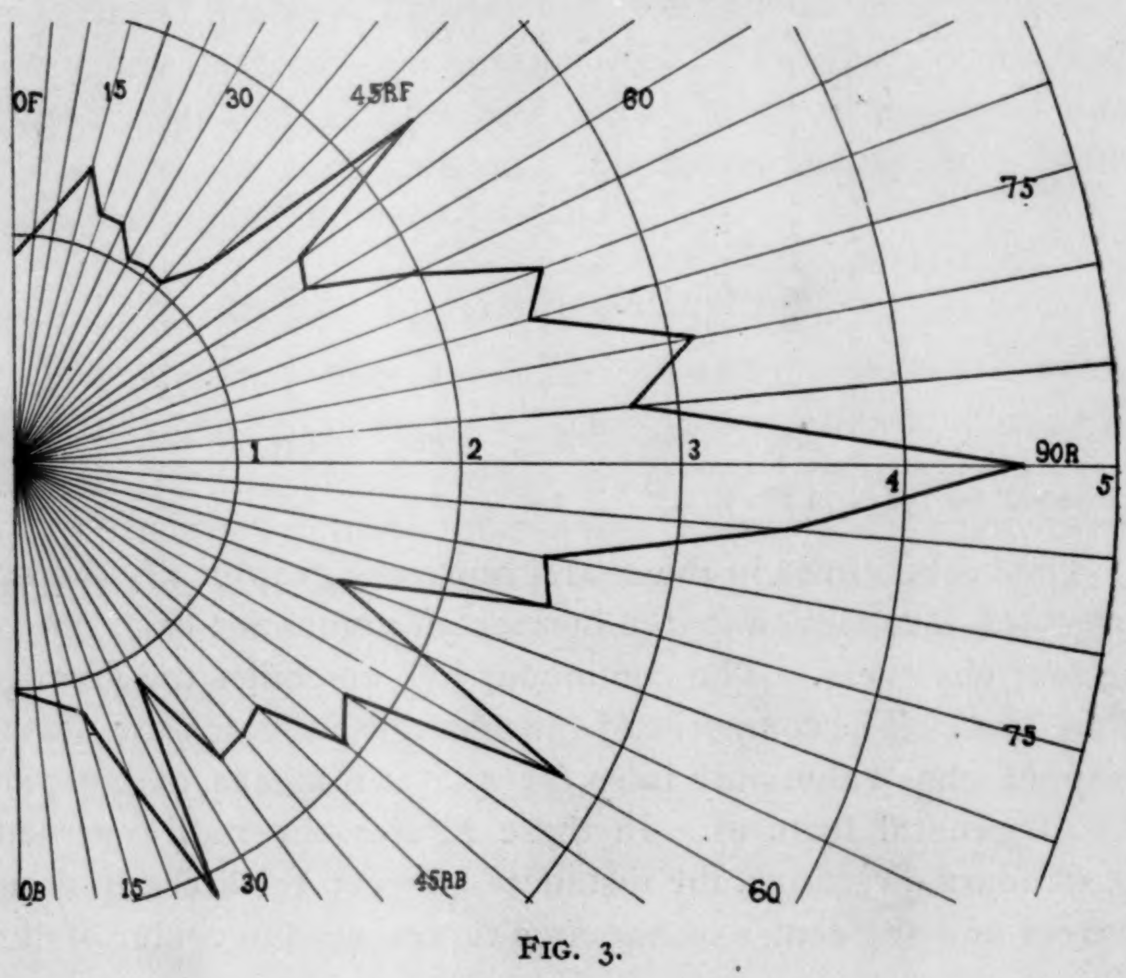


Fig. 3.

After the measurements in the horizontal planes had been completed it was thought desirable to make a more detailed investigation of a single curve. For this purpose the plane through the aural axis was chosen in which the thirty seven

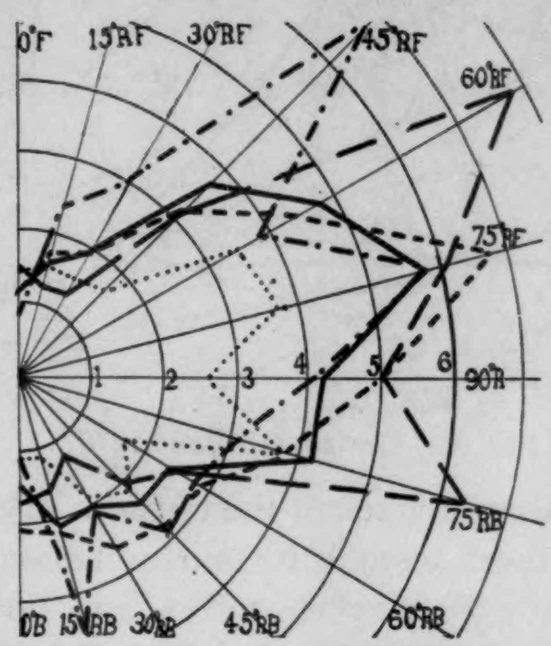


FIG. 4. Horizontal plane through the aural axis.

In Fig's 4–24, the four observers are represented by different forms of lines as follows: W ...., K ---------, B – · – · – ·, S – – – –, composite ———.

standards tested are only 5° apart. One of the four observers, *S*, was employed and gave 150 judgments at each point, in all 4,550 judgments. The curve based upon these measurements (Fig. 3) is more particularly referred to in the following.

Data in the Curves.

(*a*) In front, the localization is keenest. (*b*) In the back, it is nearly as keen. (*c*) At the side, it is least accurate. Then

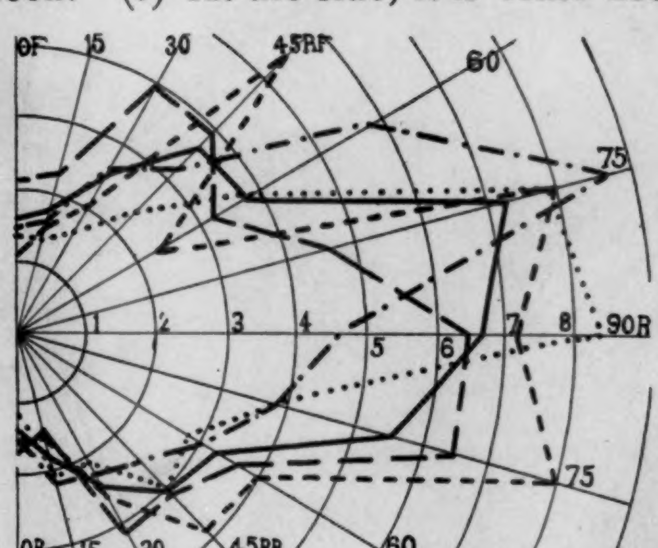


FIG. 5. Horizontal plane 15°u.

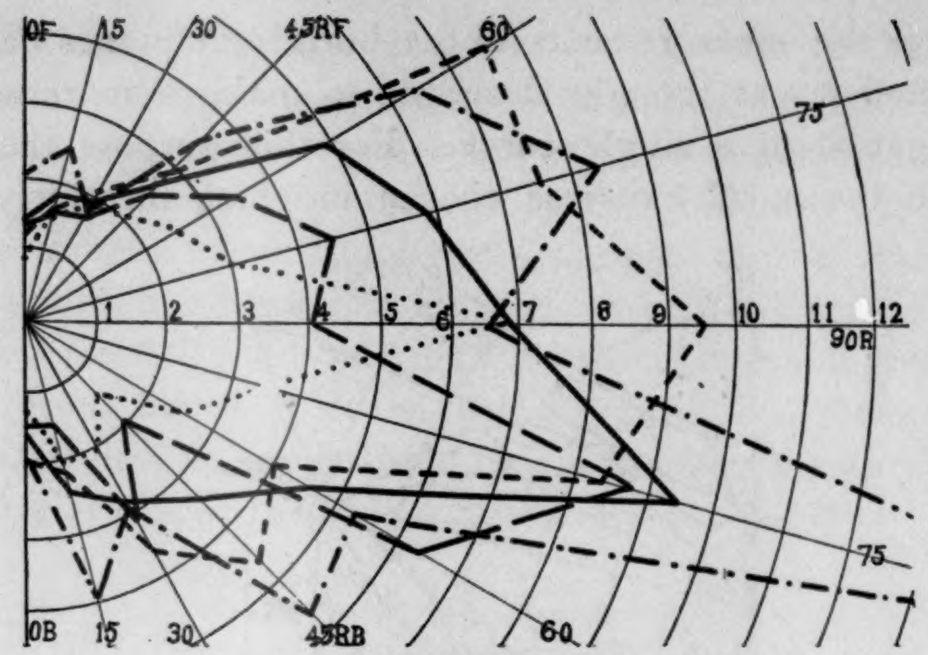


FIG. 6. **Horizontal plane 15°d.**

there are several prominences in the curves. Besides the large projection at 90°r there seem to be four quite conspicuous prominences (Fig. 3), at 15°rf, 25°rb, 50°rf, and 60°rb, which we shall designate for convenience P1, P1′, P2, and P2′, respectively, and the projection at 90°r we shall designate P3.

Glancing over the other curves we notice a quite general agreement with this one both in regard to the keenness of localization and in regard to the prominences. In Fig. 6, curve *B* and in Fig. 7, curve *K* are specially prominent illustrations of P1. In Fig. 4, curves *W* and *B* illustrate P1′. In Fig. 4, curves *B*, *S*, and *W* illustrate P2 and curves *W* and *S* illustrate P2′.

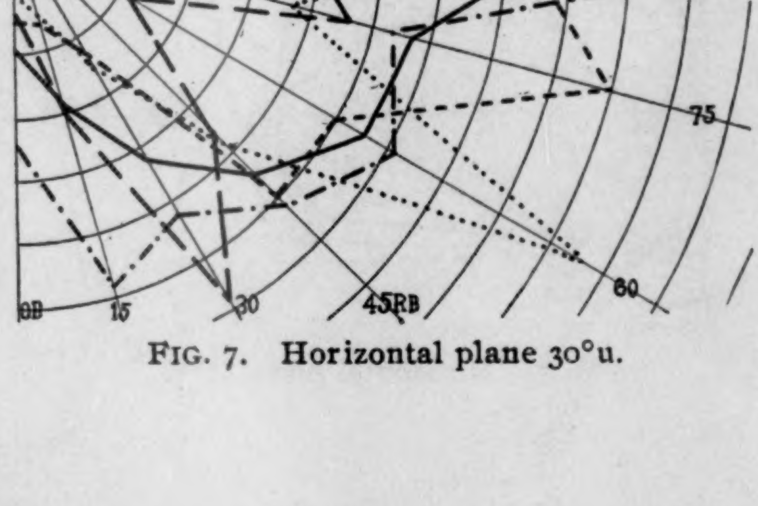


FIG. 7. **Horizontal plane 30°u.**

Discussion: Introspective and Theoretical.

Disturbing Elements. — It is necessary here to point to some items in the experiments which are disturbing elements, in the

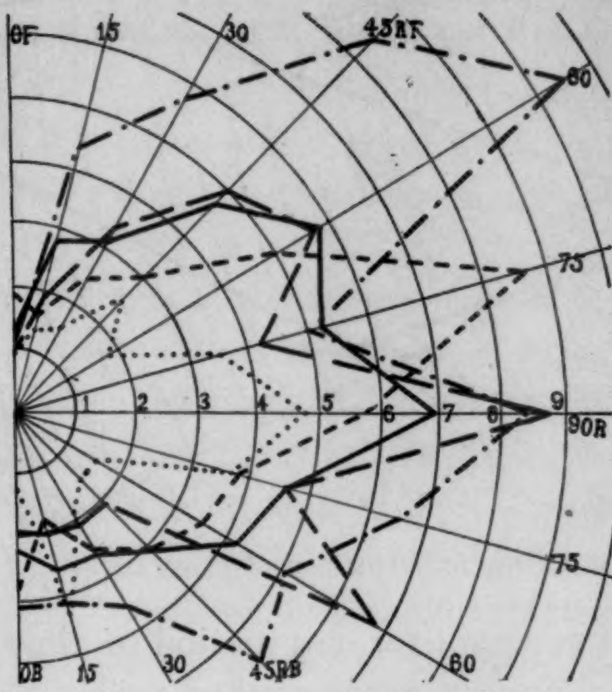


FIG. 8. Horizontal plane 30°d.

sense that they complicate the results and perhaps distort the real characteristics of the curves by obliterating or unduly accentuating the particular features. One element of this nature

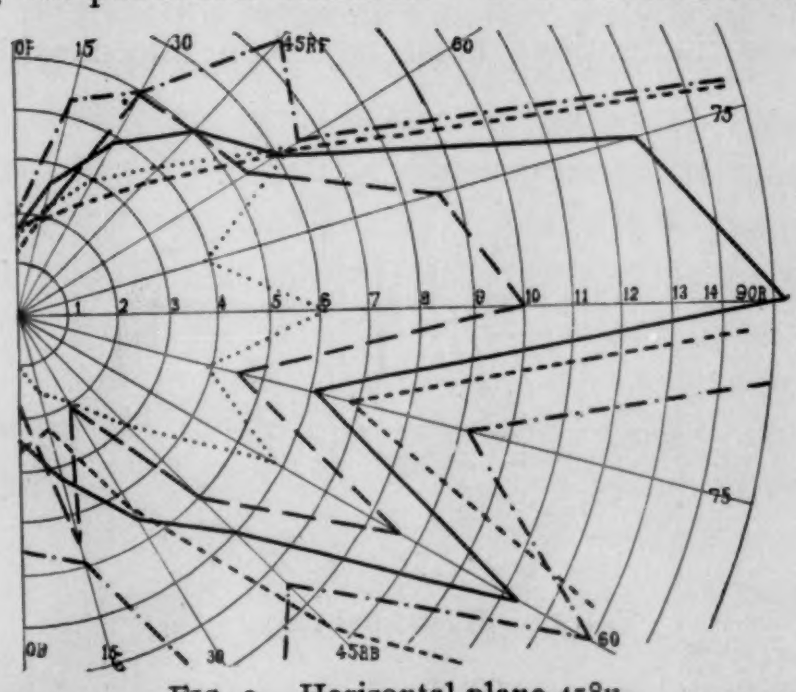


FIG. 9. Horizontal plane 45°u.

is what Kraepelin[1] calls 'Schwankungen der geistigen Leistungen.' He has shown that the mental capacity for doing work

[1] Kraepelin, 'Die Arbeitscurve,' *Phil. Studien*, XIX., pp. 459–507.

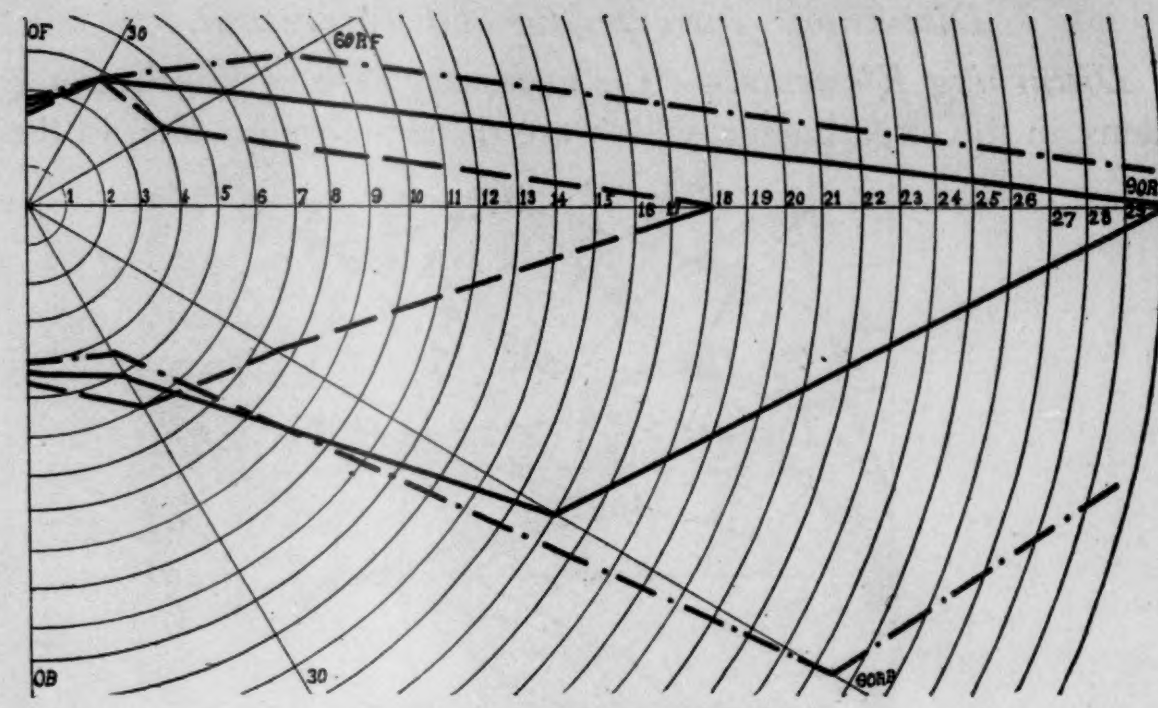


FIG. 10. **Horizontal plane 60°u.**

does not remain constant for any period of time. It fluctuates continually and the work accomplished varies accordingly. In addition to the variables which Kraepelin recognizes, there are constant tendencies to periodicity in continuous mental work, as has been demonstrated by Seashore and Kent. (See following article.)

All these fluctuations must be taken into consideration in

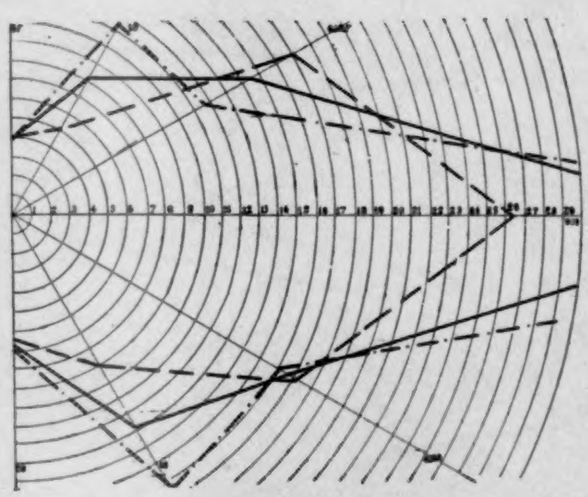


FIG. 11. **Horizontal plane 75°u.**

continuous mental work. The accuracy of discrimination varied with the wave of mental efficiency, other things being equal. That the mental conditions of the observers actually varied from standard to standard or from one group of standards to another

is probably also implied in the fact that, after all the trials at a standard had been made, the observers repeatedly remarked that they thought the localization to be rather poor at that point because of their lack of attention, or, that the localization seemed easier on account of their being able to pay attention better. A deflection in the curve that would otherwise occur may at one time be lessened and at another time be accentuated by the changes in mental capacity according to the counteraction or the coöperation of the two.

The individuality of each observer must necessarily appear in the results. This has the tendency to hide the common, universal characteristics. Although the double fatigue order has on the whole a neutralizing effect for practice and fatigue, nevertheless the fact that different parts of the records were made at different times, and consequently under slightly different conditions is responsible for some accidental features. In fact the records show that occasionally there are quite noticeable differences between the records of the two orders for the same observer.

It was found that in the process of localization the actual comparison was not usually between the standard and the sounds at the side but chiefly between the two sounds on the sides. The images of the sounds continue for some time and the observer unconsciously disregards the standard after a few stimuli have been given, and the attention is directed rather toward the two sounds at the sides. This would tend to make the distance between the sounds on the two sides the threshold of discrimination, instead of the distance between the standard and the sound on a side. However, this scarcely detracts from the validity of the results since the relative accuracy of discrimination in the various directions is the important aim.

Localization in the Median Plane Belt. — The most noticeable feature in the curves is the keenness of localization in front and in the back. This seems to imply unmistakably, that the ability to discriminate directions of sounds depends to a large extent upon the relative intensities received by the two ears. A sound so situated that it may readily reach both ears will make a change in the ratio of the intensities easily perceptible

and its direction, therefore, can be accurately perceived and easily distinguished from a sound coming from a slightly different direction. This is exactly the condition that obtains in the belt along the median plane. The points of and 0°b in each one of the charts are particular cases of this condition. In this conection a conclusion by Matsumato[1] may have some bearing: "No sound on the right or the left side was localized in the median plane. * * * No sound in the median plane was localized on the right or left side of the plane." The same observation was mentioned by Preyer.[2]

That the localization should be more accurate in front than in the back is what might be expected and is in accordance with the law of economy. The pinnæ are so attached that sounds coming from the front are received more easily. Change in intensity as well as any qualitative variations can thus be perceived more favorably. We are also more accustomed to hear sounds in front so that our attention leads us to expect and to visualize more easily in front. Professor Seashore[3] says: 'We hear more sounds from objects that we pay attention to, *i. e.*, face, than from objects that we do not attend to, *i. e.*, those behind us.'

Münsterberg,[4] and later Bloch,[5] made experiments with a similar aim testing one plane, the horizontal plane through the aural axis. In regard to front and back our results agree with the figures of Bloch. On the other hand, Münsterberg's observer localized most accurately in front but less and less accurately toward the back where discrimination was minimal, which he considers in support of his theory of reflex movements.

Localization at the Side.—Certain prominences in the curves are mentioned above. They are seemingly not individual peculiarities since they occur in the curves of all the observers; nor is it probable that they are accidental since in the

[1] Matsumato, 'Researches on Acoustic Space,' *Studies Yale Psych. Laboratory*, 1897, V., p. 5.

[2] Preyer, 'Wahrnehmungen der Schallrichtung mittelst der Bogengänge,' *Archiv. f. d. ges. Physiol.*, 1887, XL., 568.

[3] *Univ. of Iowa Studies in Psych.*, 1900, II., p. 54.

[4] *Beiträge zur experimentellen Psychologie*, Heft 2, 'Raumsinn des Ohres, p. 220.

[5] Bloch, *Das binaurale Hören*, pp. 31, 35.

special curve (Fig. 3) in which the double fatigue order was repeated several times, starting at different points and going over the same ground six times (twenty-five judgments at a time at each standard), they became more conspicuous in each successive order while other irregularities tended to vanish. The question arises, to what are these prominences due? Let us see what the introspections of the observers may suggest.

Introspective. — The following are some illustrations of frequently recurring remarks by the observers.

"At the standards 20°rf, 25°rf, 30°rf, 35°rf, and 40°rf the sounds on the right of the standard seemed slightly farther away. Then at standard 55°rf it seemed difficult to distinguish. At standards 65°rf and 70°rf the sounds toward the back seemed decidedly nearer. At 75°rf and 80°rf there was again no very definite means of localization. At 85°rb, 80°rb, 75°rb, and 65°rb the sounds toward the front seemed stronger and nearer. At 60°rb it again seemed difficult to distinguish the directions."

"It seemed especially difficult to localize at standard 25°rb. There was apparently no means of discrimination."

Standard 45°rf. "There is a difference in quality. Those toward the back have lower partials and are richer while those toward the front are thinner."

Standard 75°rf. "Those toward the back seem nearer and those toward the front seem farther away and thinner."

Standard 75°rb. "Those toward the back seem thinner."

Standard 60°rb. "The sounds toward the back are lower."

Standards 60°rb, 45°rb, and 30°rb. "In nearly all trials the sounds back of the standards seemed thinner as if heard 'around the corner of a building' in comparison with those in front of the standards."

These quotations from the records serve to make some, though not very definite, suggestions. (*a*) There seem to be certain directions where the localization is more difficult than in others, apparently because there is no means of discrimination. (*b*) There are relative differences in intensity for different directions. (*c*) Although the sounds were objectively at the same distances for all directions the observers felt quite sure that they did not seem to be at the same distances. (*d*) Then, variations in pitch, richness of sound, etc., are mentioned.

In order to determine more precisely the significance of these data and, if possible, to find new elements, a special set of tests was made upon four other observers *Wi*, *H*, *Ch*, and *Kl*, who were entirely ignorant of the results thus far obtained. Three typical standards were chosen namely, 45°rf, 90°r, and 45°rb, in each one of three horizontal planes, 30°d, 0°, and 30°u.

The apparatus was the same as in the regular experiments but the method was slightly different. The standard was given

TABLE I.

STANDARD 45°RF IN EACH OF THE THREE PLANES.

Observer.	Planes.	Forward.							Backward.						
		Fainter.	Further.	Less Clear.	Pitch. h.	Pitch. l.	Richer.	Misplacement.	Louder.	Nearer.	Clearer.	Pitch. h.	Pitch. l.	Thinner.	Misplacement.
	30°u	4(1)		2		2			1(4)	(1)			3		
Wi	0°	(2)	2			1			4	1	1	2	1		1u
	30°d	2(1)	1	(2)		3			2(1)		1	1	2		
	30°u	(4)			1								4		2d
H	0°				5				2		1		2		
	30°d	(3)			1			2u			1		4		
	30° u		1(2)		3			2u 1d		1(5)			2		1u
Ch	0°		1(2)		2				1				4		
	30°d	(1)	1		4			3u	3				4		1u
	30°u	(1)	1					3u	(3)				2		3d
Kl	0°	4						2u	5						1d
	30°d	(1)	(4)					2u	4	3					1d
		10(14)	7(8)	2(2)	16	6			22(8)	5(6)	4	3	28		

The numbers in parenthesis indicate the judgments that were contrary to the column under which they are given.

TABLE II.

STANDARD 45°RB IN EACH OF THE THREE PLANES.

Observer.	Planes.	Forward.							Backward.						
		Louder.	Nearer.	Clearer.	Pitch. h.	Pitch. l.	Richer.	Misplacement.	Fainter.	Further.	Less Clear.	Pitch. h.	Pitch. l.	Thinner.	Misplacement.
	30°u	4		3	1	1			4(1)				2		
Wi	0°	4	3		2			1u	2(1)	2(1)			4		
	30°d	5(1)		1	1	1	1		3(1)						
	30°u	3			2								4		1d
H	0°	3		3	2		1				(2)		3		
	30°d	2		2	3		1						3		3d
	30°u	2						3u 1d					3		5d
Ch	0°	3	1		1	2			(1)	2		1(?)	2		
	30°d	3		1		1			(1)	1(1)		1			2d 1u
	30°u	4		1				5u	(4)		1(1)		2		1d
Kl	0°	5		1				3u	(2)(?)						3d
	30°d	3	5	1				2u		5					
		41(1)	9	13	12	5	3		9(11)	10(2)	1(3)	2	23		

and then a sound on one of the two sides so far from the standard that the observer could easily tell its direction, which was in each case determined by a few preliminary trials. Each observer gave ten judgments at each standard. Before the tests were begun, the observer was told to describe as accurately and carefully as he could the differences that he noticed between the sounds from the directions under comparison at any given trial. The results thus obtained are given in the tables.

TABLE III.

STANDARD 90°R IN EACH OF THE THREE PLANES.

Observer.	Planes.	Forward.										Backward.									
		Intensity.		Distance.		Clearness.		Pitch.		Richness.	Misplacement.	Intensity.		Distance.		Clearness.		Pitch.		Richness.	Misplacement.
		m.	l.	m.	l.	m.	l.	h.	l.	m.l.		m.	l.	m.	l.	m.	l.	h.	l.	m. l.	
	30°u	1	4			1							5								2u
Wi	0°	3	1		1			3		1	2u	4	1						4		1u
	30°d	5			1	1			2				5	1			1		5		
	30°u	3				1		2			1u	1				1			3		
H	0°	2				1		1				1							4		
	30°d	3				1		2											3		2d
	30°u								2		3u 2d	1							1		3d 1u
Ch	0°	2			2			1				2			2				3		
	30°d	2			1			2			1u	1					1		5		
	30°u	1			2	1					4d			1			1				4u 1d
Kl	0°	2	3	3								4									3d
	30°d	2			3										1				1		4d
		26	8	3	10	6		11	4	1		14	11	2	3	1	3		29		

(*a*) Intensity is the most prominent feature. In Table I. we notice that under the rubric *backward* twenty-two are said to be louder and eight fainter. In Table II. under *forward*, forty-one are louder and one fainter. In Table I. (standard 45°rf), *backward* means nearer to the aural axis and, in Table II. (standard 45°rb), *forward* means nearer to the aural axis. This indicates that for these particular positions sounds nearer the aural axis seem more intense. On the other hand, in Table I. under *forward*, *i. e.*, farther from the aural axis, ten are fainter and fourteen louder; and in Table II., under *backward*, *i. e.*, farther from the aural axis, nine are fainter and eleven louder. There is no definite inclination for the converse of the above statement, that sounds farther from the aural axis seem less

intense. But the implication probably is that the statement, the nearer a sound is to the aural axis the louder it seems, is true only for the immediate vicinity of the aural axis, and that if we go beyond certain limits the opposite may possibly be true as one of the quoted introspections indicates. In Table III. (standard 90°r), under *forward*, twenty-six are louder and eight fainter. The tendency seems to be to designate those *forward* as louder. Hence the point where a sound seems loudest, *i. e.*, the subjective aural axis, is probably farther forward than the objective aural axis.

(*b*) Distance is frequently mentioned. On the ground that change in intensity signifies change in distance, the figures under this head in the tables would have the same meaning as the figures under intensity. Sounds nearer the aural axis seem nearer to the head than those farther away from the axis.

(*c*) Clearness and richness are also spoken of, and here as for intensity and distance sounds nearer the aural axis are clearer and richer.

(*d*) In each table it may be noticed that the sounds *forward* are said to be higher in pitch and those *backward* are said to be lower. What this item means is not entirely clear. It may be that under it other elements are included which the observers could not very well designate by any other name, or the word forward may suggest higher and the word backward lower pitch.

(*e*) There are two kinds of misplacements, upward and downward, most of which become intelligible when we reduce them to terms of distance or intensity. For example, if, at the standard in the front upper quadrant, the sound *forward* is said to be up, or the one *backward* is said to be *downward*, it probably means that it seems farther or nearer respectively. But knowledge of the positions of the sounds tells that it is neither farther nor nearer in a radial direction, therefore it is shifted up or down. Most of the misplacements are probably accounted for upon this basis. However some may be due to other causes such as expectation and other differences in subjective and objective conditions.

Since it has been shown that distance (or intensity) is a potent factor in localization, another brief set of experiments

was planned with the view to specify it more definitely. Again the same apparatus was used. Five observers, M, We, Se, Bu, and Ho, who were entirely naïve in regard to the structure of the apparatus and the method of experimentation and its purpose were engaged. Before the observer was brought to the apparatus he was blindfolded to avoid suggestions that might be gained from the structure of the apparatus. The observer was seated in the regular position within the perimeter; a sound was given in front and then the receiver was moved to one of the regular standards (horizontal plane through the aural axis) in the right front quadrant and there another sound was given. The observer then, not knowing that the sounds were actually at the same distances, estimated in inches the comparative distances of the two sounds. It was not prohibited to judge them to be at the same distance. This was repeated five times for each standard by each observer.

In a similar manner tests were made in the rear quadrant where the comparison, however, was with the sound directly back instead of in front. The essential aim was to make a distance comparison of all directions with one direction.

TABLE IV.

	0°f In.	15°rf In.	0°f In.	30°rf In.	0°f In.	45°rf In.	0°f In.	60°rf In.	0°f In.	75°rf In.	0°f In.	90°r In.
Bu	37	42	38	39	35	43	36	40	36	38	36	40
Se	28	31	26	27	28	26	25	26	22	20	27	20
Ho	26	23	22	22	24	24	35	26	27	17	38	28
We	23	32	22	33	24	29	22	28	23	33	24	33
M	32	33	37	39	39	38	36	37	35	30	35	29

	0°b In.	75°rb In.	0°b In.	60°rb In.	0°b In.	45°rb In.	0°b In.	30°rb In.	0°b In.	15°rb In.
Bu	53	48	48	45	48	48	44	46	43	41
Se	27	24	26	25	28	26	23	25	26	29
Ho	32	26	42	30	36	32	29	31	30	32
We	24	32	22	37	24	31	22	30	23	32
M	38	35	39	36	37	41	34	38	36	38

	0°f In.	15°rf In.	30°rf In.	45°rf In.	60°rf In	75°rf In.	90°r In.	75°rb In.	60°r b In.	45°rb In.	30°rb In.	15°rb In.	0°b In
Bu	40	45.4	41.1	49.1	44.4	42.2	44.4	36.3	37.5	40.0	41.8	38.1	40
Se	40	44.3	41.5	37.1	41.6	36.3	29.6	35.5	38.4	37.1	43.4	44.6	40
Ho	40	35.4	40.4	40.0	29.7	25.2	29.5	32.5	28.6	35.5	42.8	42.7	40
We	40	55.6	60.0	48.3	50.9	57.4	55.0	53.3	67.3	51.7	54.5	55.6	40
M	40	41.3	42.1	39.0	41.1	34.3	33.1	36.8	36.8	44.3	44.7	42.2	40
Av.	40	44.4	44.7	42.7	41.5	39.1	38.3	38.9	41.7	41.7	45.4	44.6	40

The results are shown in Table IV. The upper portion of the table gives the averages of the estimates of each observer. In the lower section the ratios of the pairs of comparison are reduced to the basis of 40 inches, the actual distance of the sounds. For example the first observer's estimate 0°f 37 and 15°rf 42; then, 37 : 42 : : 40 : 45.4, etc.

These figures are represented graphically by Fig. 12.

(*a*) Sounds are judged nearer in three places, in front, in the back, and at the side.

(*b*) Between these regions, about the middle of each quadrant, they seem farthest away.

Theoretical.—It remains to establish a connection, if possible, between the introspections, the results of the special tests, and the prominences in the curves.

Since in some directions sounds seem nearer and stronger than in others, and since there seem to be differences in quality for different directions; in short, since there are variations in the data upon which the localization depends, it seems reasonable to infer that there must be corresponding changes in the process of discrimination of directions. It has been stated that in front localization depends upon the relative intensities received by the two ears and that here a sound seems nearer than an equidistant sound farther toward the right. If a sounding receiver be moved from 0°f toward the right it apparently recedes at the same time, seeming to be farthest away about the middle of the quadrant.

This leads to the assumption that there is a change in the basis of localization from the condition in which sounds compared at any one time are seemingly at the same distance and of the same intensity to the condition in which the sound at the right of the standard appears farther away.

Now if the receiver be moved still farther to the right it will again seem to approach and become more intense, reaching its greatest intensity at or near the aural axis. A sound farther toward the right would now be stronger and nearer than one not so far toward the right, which would effect another change in the method of localization. Besides, there is here also the addition of qualitative elements. Sounds nearer to the aural

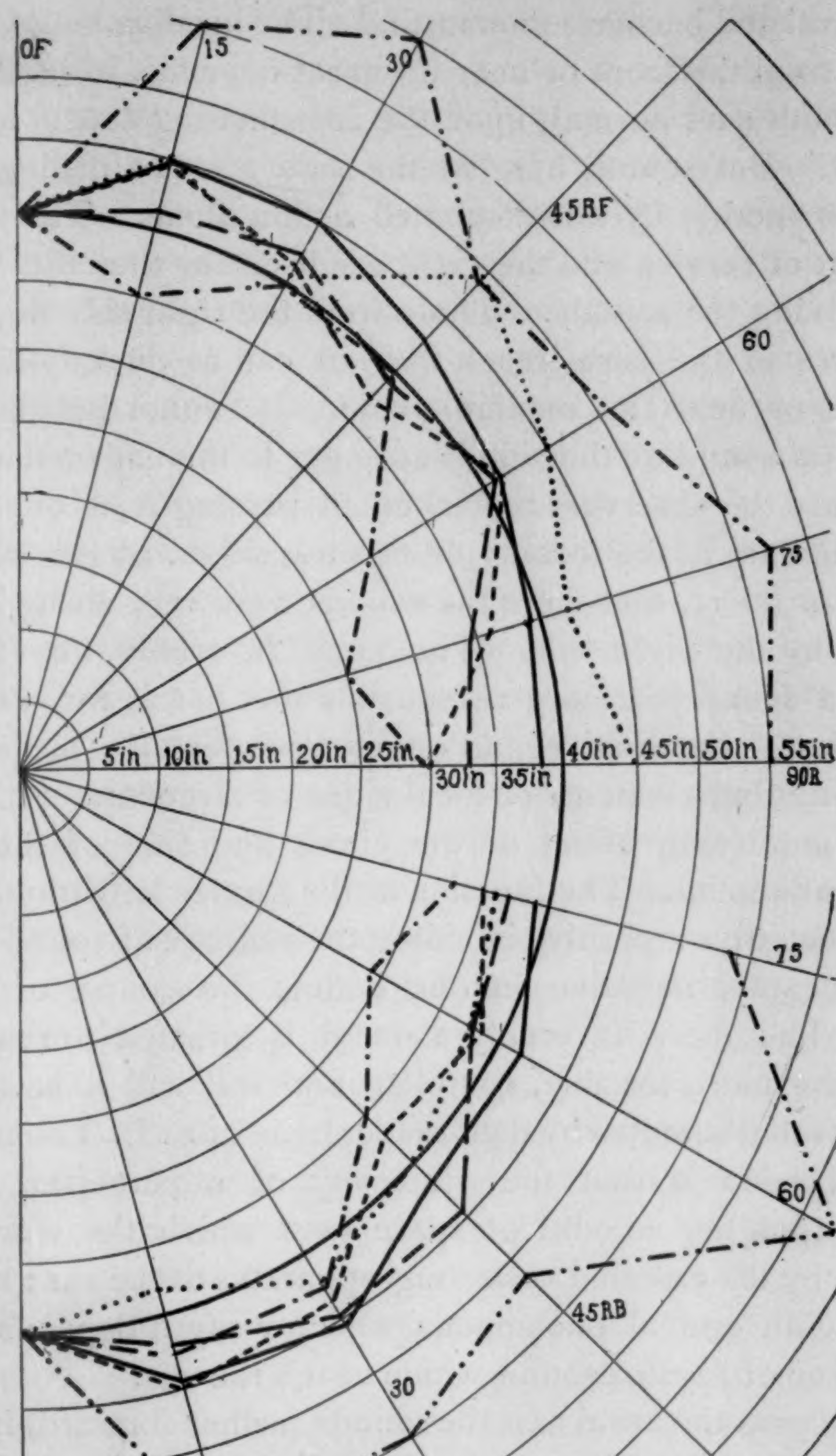


FIG. 12.

Bu ····, Se - - - - -, Ho - · - · - · -, We - · · - · · -, M - - - -, composite ———.

axis seem stronger, nearer, clearer, and richer than those not so near to it. That is, the localization in this region ceases to

be binaural and becomes monaural.[1] The localization of sounds coming from the front or near the front depends, in individuals having both ears normal, upon the coördinating function of the two ears. But sounds here at the side are not distinguished from one another by this combined action alone. The left ear drops out of service and the right ear becomes the chief means of perceiving the sounds. Those from the right side do not, in the nature of the case, reach the left ear as directly as from points in or near the median plane. It cannot be otherwise than that a sound on the side is stronger to the ear on that side. Frequently the observers remarked in passing from one standard to another in the locality of this transition, as for example at 45°rf or 60°rf, that there the sounds were very strongly perceptible to the right ear. The more favorably an ear can receive a sound the more responsible that ear is for a correct localization. Qualitative and quantitative features are among the determining elements or local signs of direction.

The modifying effect of the pinna and side of the head become influential. The function of the former is twofold, positive and negative: positive in aiding the passage of sound waves to the meatus, negative in obstructing the course of sound waves. The more favorably a sound is situated to reach the meatus the more forcible, complete and full will it be. This fact was well illustrated by the pseudophone of S. P. Thompson.[2] His conclusion is that the 'intensity of a perceived sound depends upon the amount of space over which the waves are gathered by the external collecting apparatus of the ear; and by analogy with optical phenomena we may say it depends upon the number of rays of sound which reach the ear.'

As we pass the aural axis the sounds farther forward, instead of backward as before, seem louder and more distinct. Hence there is a third transition point at the subjective aural axis. In the rear quadrant sounds seem most distant about the middle of the quadrant and, corresponding to the two transition points in the front quadrant, there are two in the rear quadrant since the conditions of localization are practically the same at ob as at of.

[1] The terms binaural and monaural are not used in their ordinary absolute meaning.

[2] Thompson, 'The Pseudophone.' *Phil. Mag.*, VIII., 1879, pp. 385–390.

In all there are five transition points (T). The first T1, lies between 0°f and 45°rf, the second, T1′, is located symmetrically in the rear quadrant, the third, T2, and the fourth, T2′, are near or just beyond the middle of the quadrants, and the fifth, T3, is at the aural axis. T1 is essentially a change in binaural localization 'from the condition in which sounds compared are seemingly at the same distance and of the same intensity to the condition in which the sound at the right of the standard appears more distant.' T2 is essentially a transition from binaural to monaural localization. T3 is a change in monaural localization, *i. e.*, a reversal of the monaural process. More will be said below in regard to this transition point. T2′ and T1′ are reversals of T2 and T1 respectively.

The positions of the transition points correspond to the positions of the prominences in the curves. T1 corresponds to P1, T1′ to P1′, T2 to P2, T2′ to P2′, and T3 to P3. Now, the relation between the two is in the fact that change in the data and elementary processes involved in localization, *i.e.*, change in the basis of discrimination must cause more or less confusion on the part of the observer. In several of the introspections the observation is made that at some standards it was especially difficult to localize. It may be noticed that these directions correspond to the positions of the prominences. That these transitions resulted in confusion is further supported by the introspective remark of the observers that a definite distinction could be noticed between the standard and the sound compared with it but that the observer could not tell with certainty on which side of the standard the second sound was. Consequently more errors were made, and hence the prominences in the curves. But in a large number of trials the observer soon learned to interpret these distinctions correctly, in part at least. In other words he became adapted to the modified method. That such adaptation actually occurred is quite apparent from the distribution of the errors in the records. In 75 per cent. of all such transitions the records show that nearly all errors made at a standard were made in the first half of all the trials made with that standard. This clearly indicates that in the second half the observer had learned to interpret more correctly the

distinctions that were already recognized in the first half but not understood.

In regard to P3 it should be mentioned that beside the fact that it is a transition, there is another condition involved. There must be a point in the aural axis or thereabouts where the coördinating function of the two ears reaches its minimum, or where monaural localization reaches its maximum. If the two ears render any assistance to each other in the perception of direction there must be a point where this mutual effect is least, and consequently tends to make discrimination less accurate. Then there is also the presence of confusion points. A telephone moving from front toward back comes to a position in or near the aural axis where it has its greatest monaural intensity. The locus of this point at different distances from the head was above designated as the subjective aural axis. If the monaural intensity is maximal in the subjective aural axis there must be, for each point on one side of the axis, a point on the opposite side of the axis with similar characteristics. That is, a sound near the subjective aural axis permits of more than one interpretation in terms of perception, and hence a system of confusion points.

In recent years, the so-called secondary, qualitative factors have been recognized as important elements of localization. Intensity was held as a very essential factor but recent investigations[1] show that we are not justified in laying so much emphasis upon it. Intensity alone is not sufficient to account for all the features of localization. The fact that monaural localization has been demonstrated indicates a more complicated basis for the perceiving of direction of sounds. Careful observation and introspection point to the presence and importance of qualitative data in the process of localization.

Referring again to the curve of Bloch, we find that it does not indicate any prominences or deflections beyond the general fact of poorer discrimination at the side. The chief reason for this is that the standards which he tested are farther apart,

[1] Angell and Fite, 'Monaural Localization of Sound,' PSYCH. REV., 1901, VIII., pp. 225–246; pp. 449–458.

Angell, 'Significance of Partial Tones,' PSYCH. REV., 1903, X., pp. 1–14. Pierce, *Studies in Space Perception.*

namely 22.5°. In the charts, with standards 15° apart, the prominences do not appear so regularly as in Fig. 3, with standards, 5° apart.

Series II. Vertical Planes.

The immediate aim of this series is to determine the power of discrimination between directions of sounds in vertical planes.

The apparatus and its arrangements are exactly the same as in the first series with one exception. It was possible in the first series to procure uniformity in the reflection of sounds by keeping the source of the sound in the same locality and allowing the observer to take different positions for the various standards. This could not be done in the vertical measurements. To overcome this difficulty a screen was devised consisting of

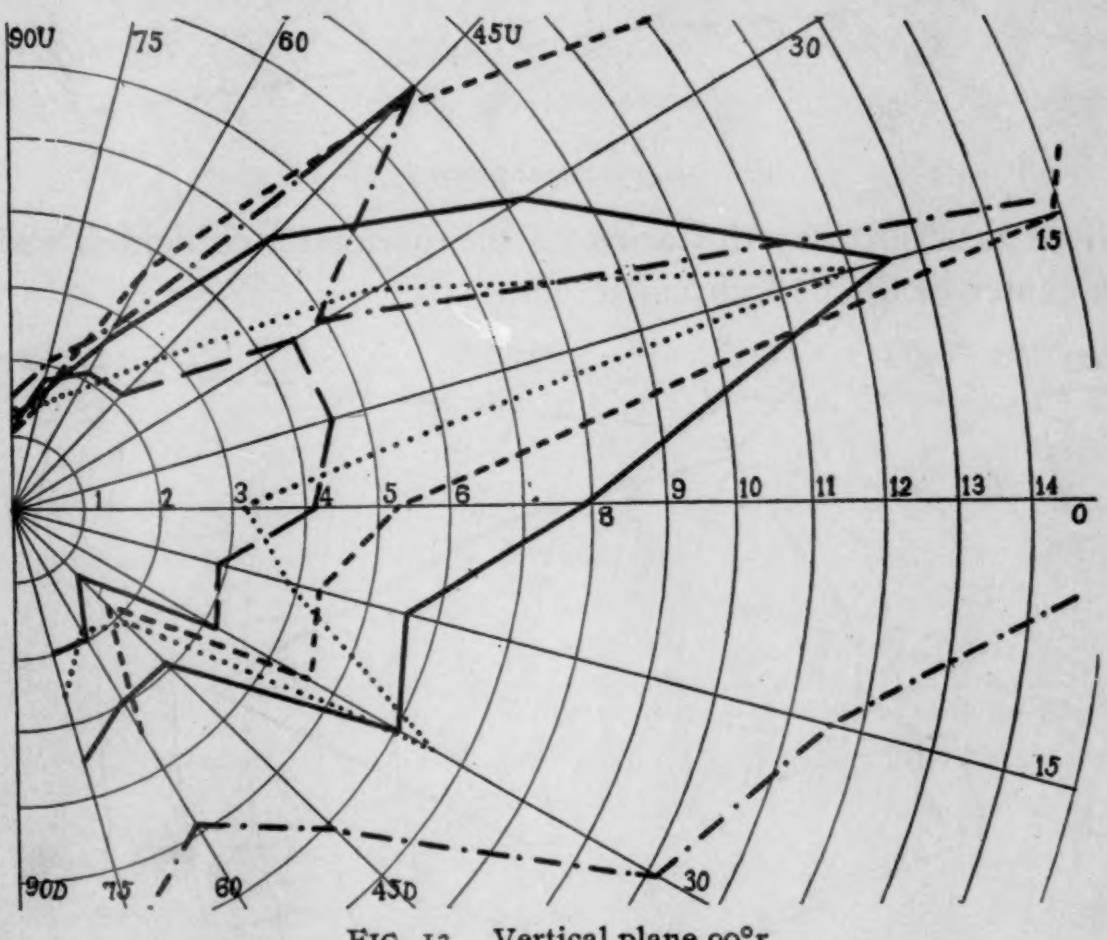


Fig. 13. Vertical plane 90°r.

a frame built of iron pipes over which a canvass was stretched. The screen thus constructed had the shape of a hollow cylinder 3.40 meters in diameter and 2.70 meters in length. It was so situated with reference to the perimeter that the center of the

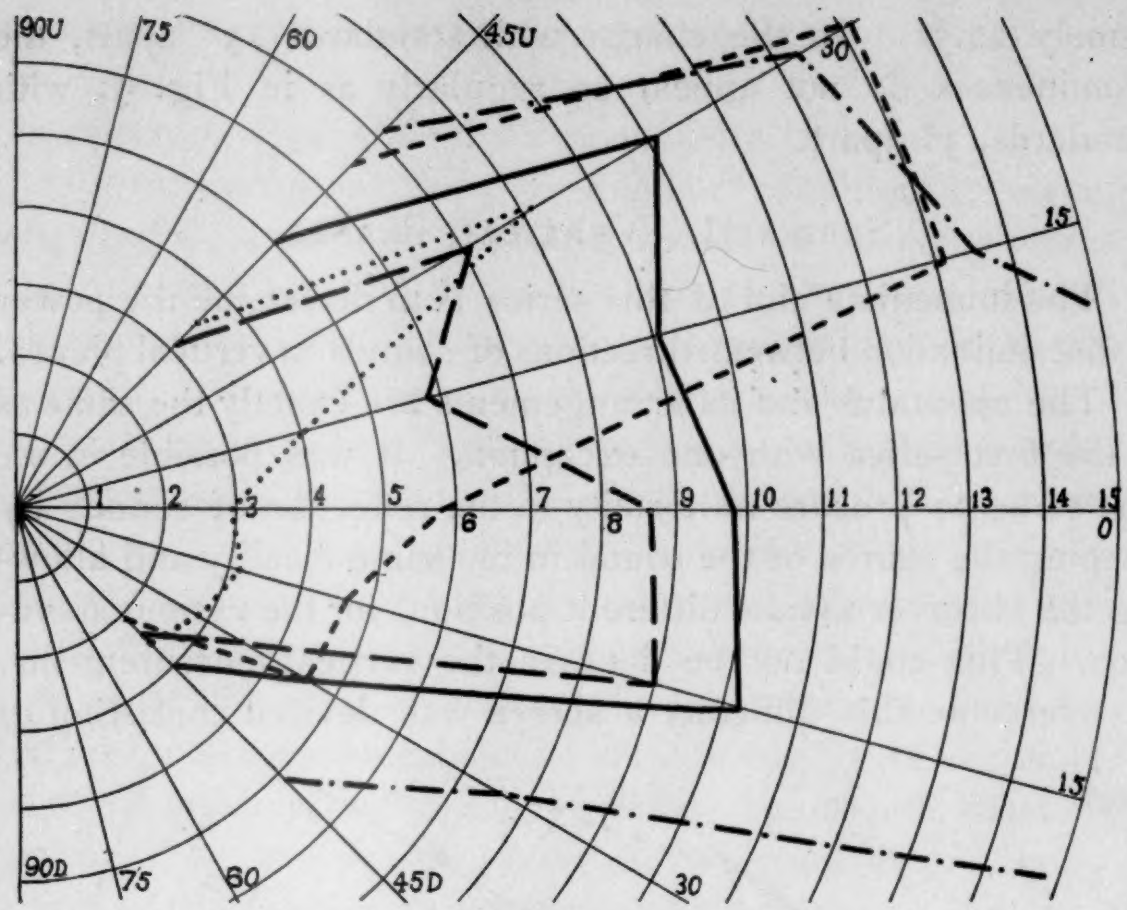


FIG. 14. Vertical plane 75°rf.

sphere described by the arms of the perimeter coincided with the center of the cylindrical screen.

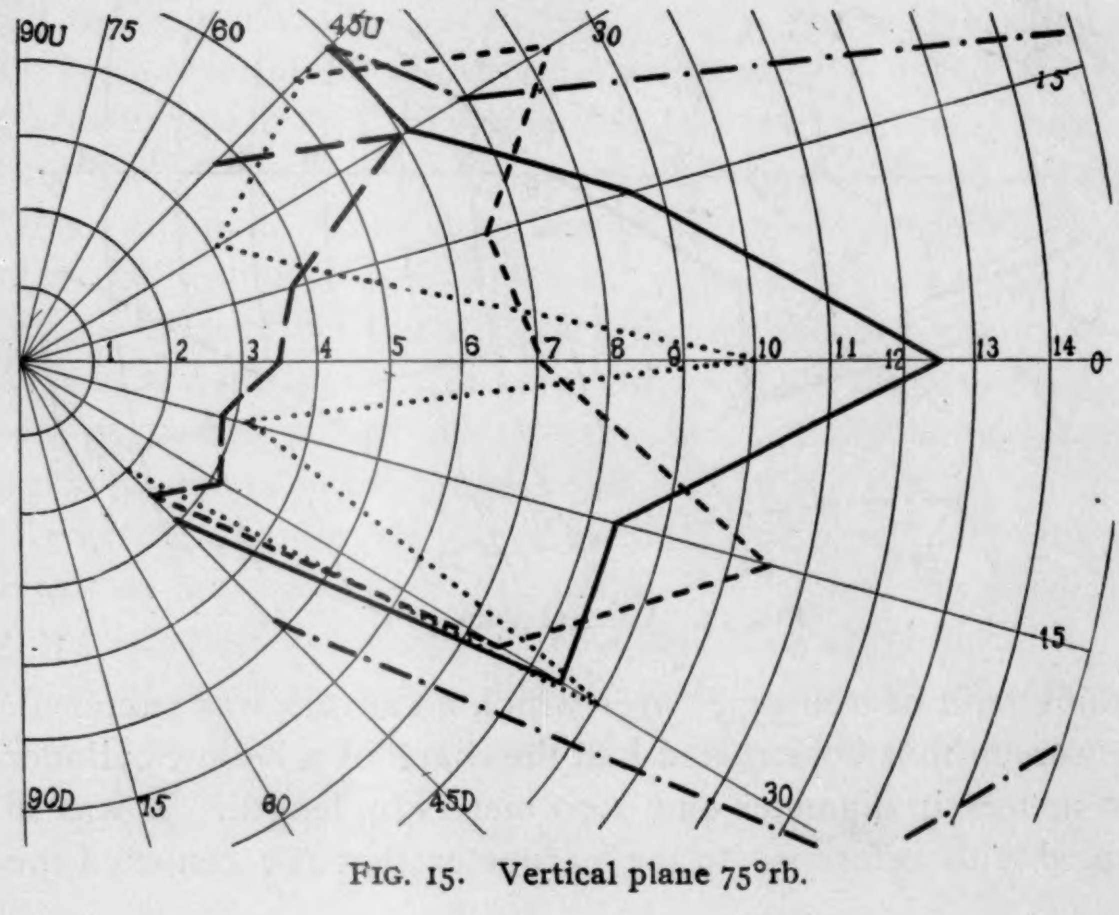


FIG. 15. Vertical plane 75°rb.

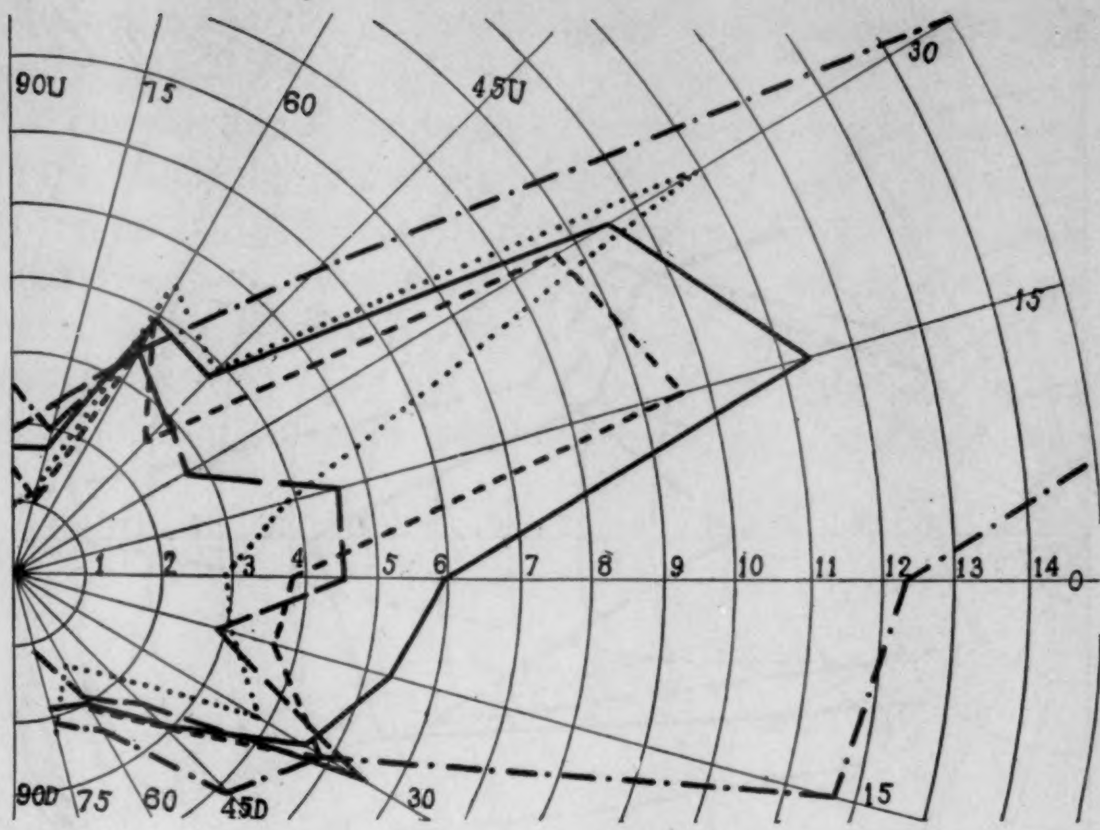


FIG. 16. Vertical plane 60°rf.

A brief but careful test was made of one of the vertical planes to discover whether the screen would be sufficient to give uniform reflection. The observer took a horizontal position on

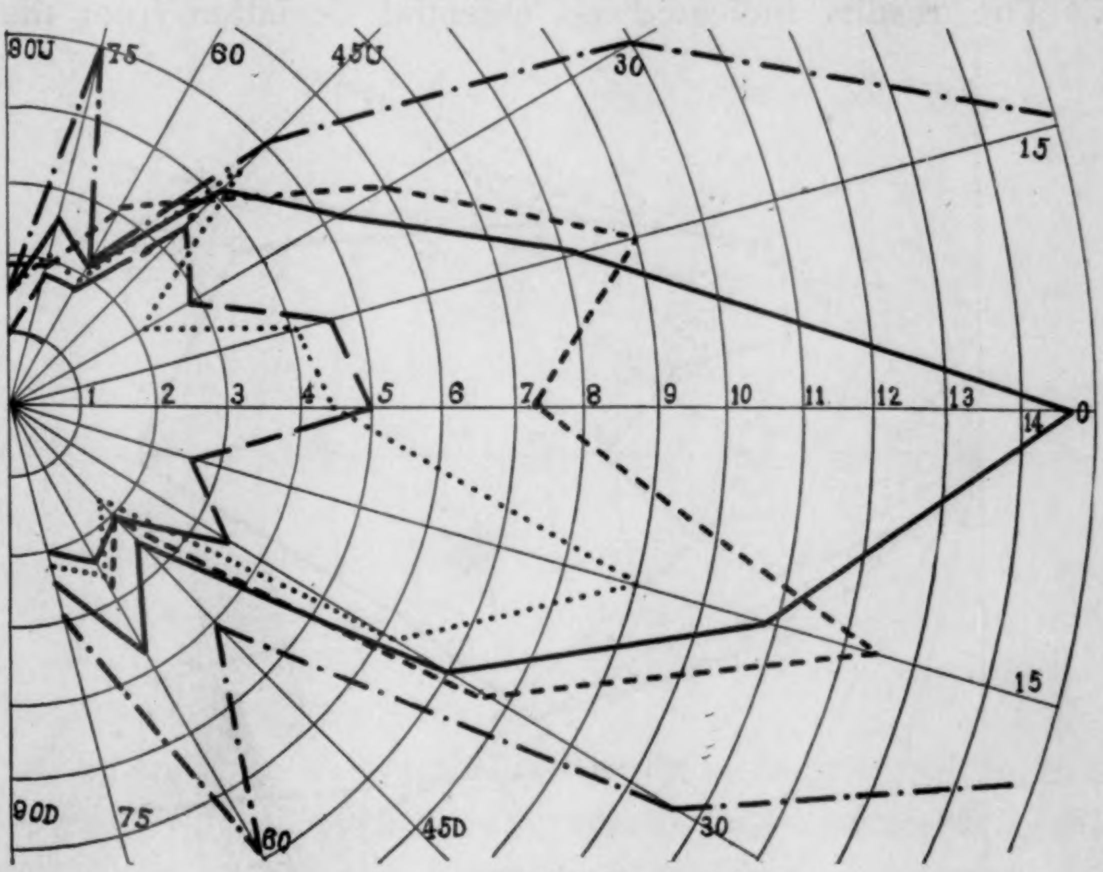


FIG. 17. Vertical plane 60°rb.

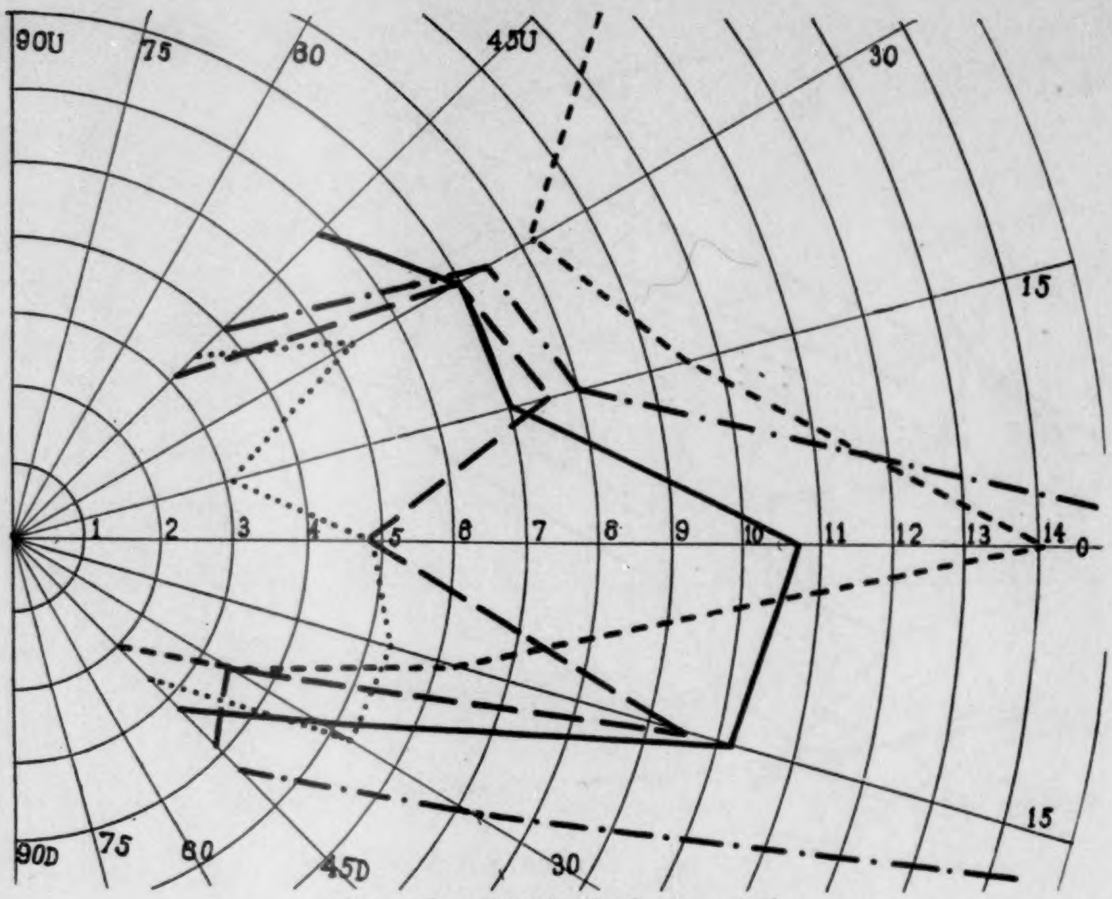


FIG. 18. Vertical plane 45°rf.

a bench constructed with as little material as possible. The stimuli were given in the same manner and locality as in Series I. The results indicated no essential deviation from those

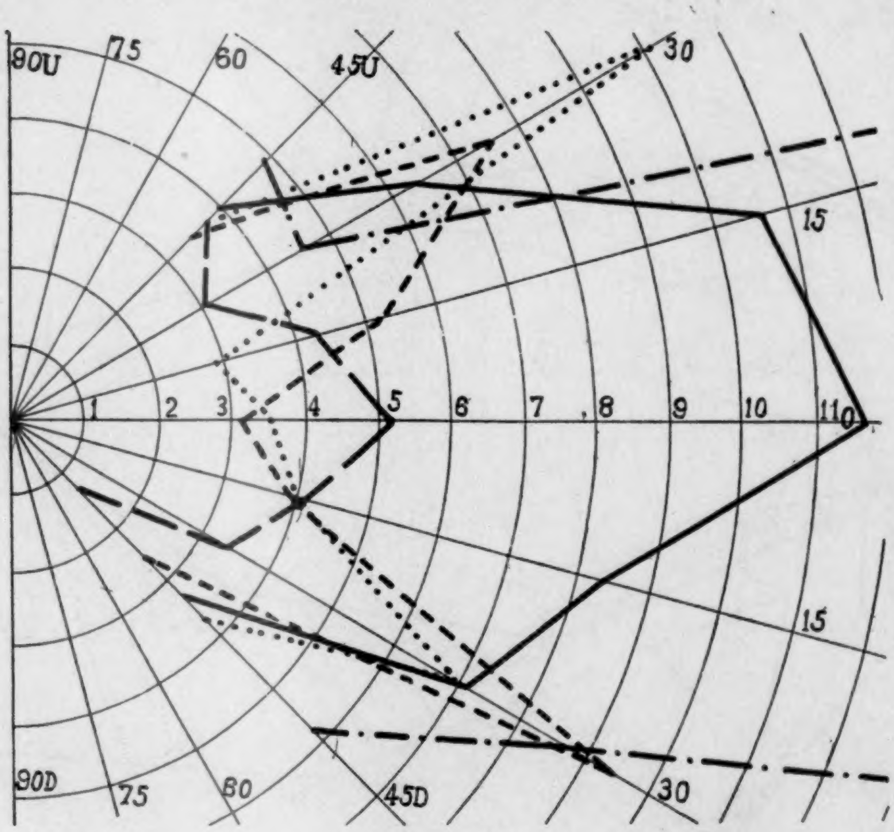


FIG. 19. Vertical plane 45°rb.

obtained when the screen was used and the observers had the upright position.

The standards, one hundred and twenty-five in number, are in the following vertical planes (see Fig. 2): 90°r, 75°rf, 75°rb, 60°rf, 60°rb, 45°rf, 45°rb, 30°rf, 30°rb, 15°rf, 15°rb, and the median plane. The planes 90°r, 60°rf, 60°rb, 30°rf, 30°rb, have twelve standards each, 15° apart. The point 90° down was not tested. The planes 75°rf, 75°rb, 45°rf, 45°rb, 15°rf, and 15°rb, have seven standards each, 15° apart and ranging

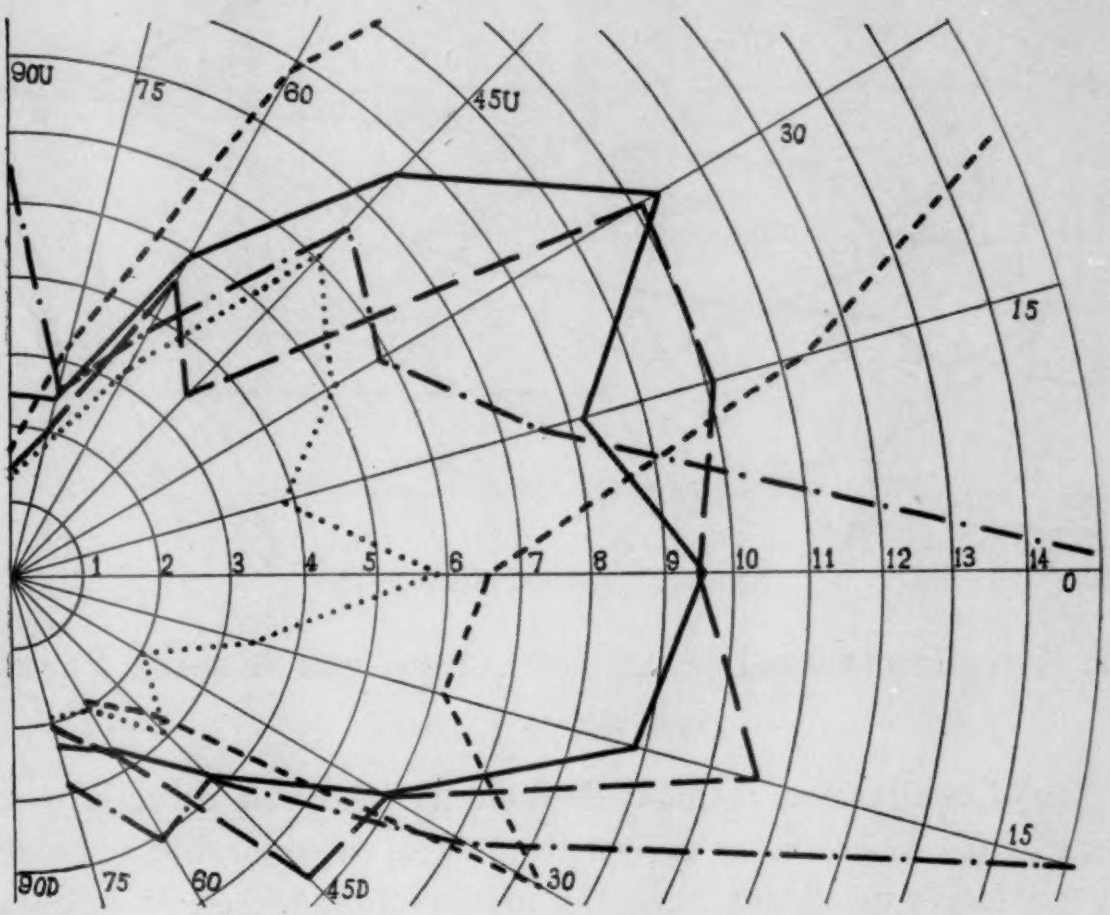


FIG. 20. Vertical plane 30°rf.

from 45°u to 45°d. In the median plane are twenty-three standards.

Each of the four regular observers, *W*, *K*, *B*, and *S*, gave fifty judgments at each standard passing through the entire series of points in the double fatigue order, which gives in all about 25,000 judgments.

The charts are constructed on the same principle as in the foregoing series but here a degree has the same distance-value throughout, namely, 17.5 mm.

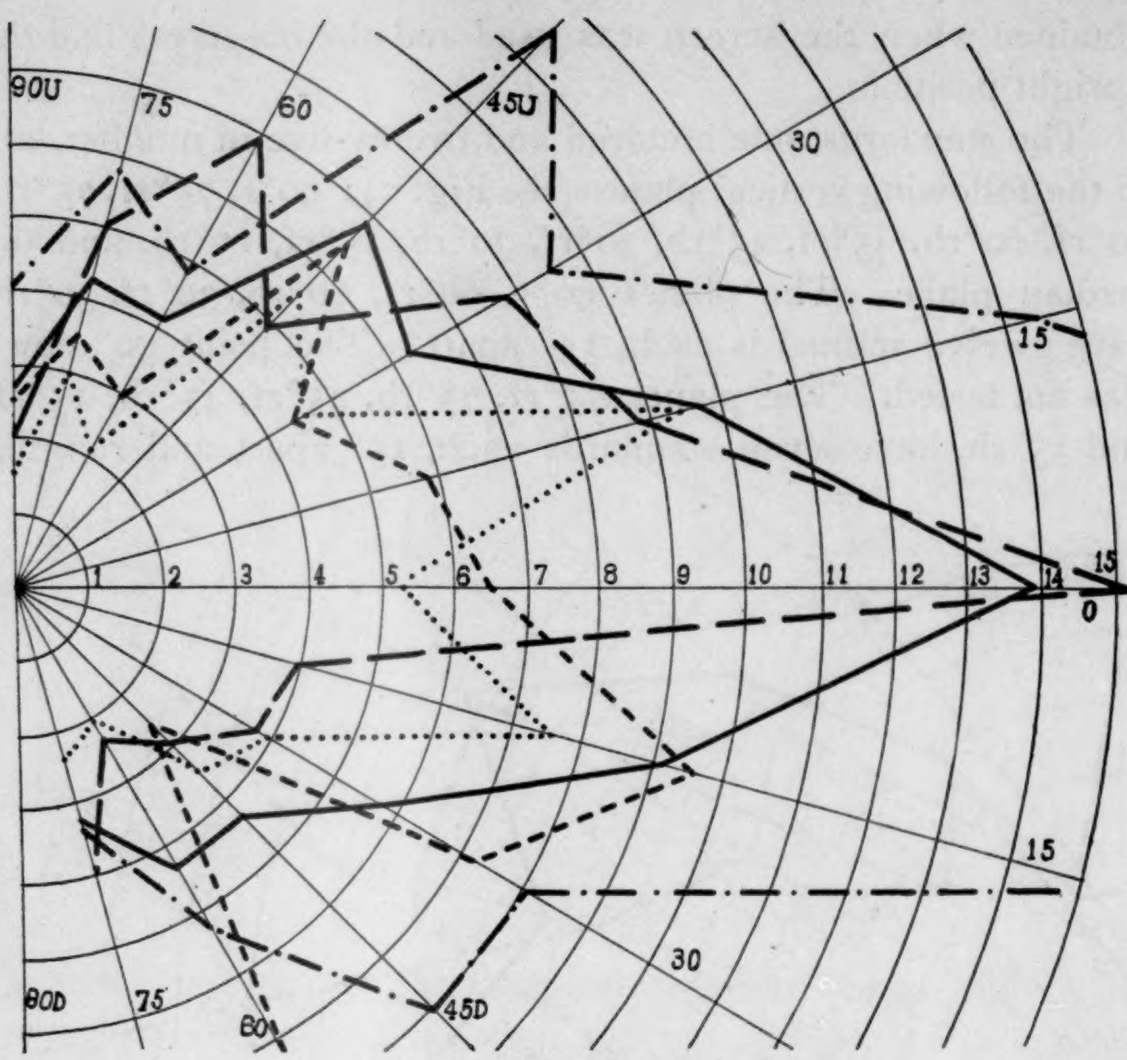


FIG. 21. **Vertical plane 30°rb.**

A. THE VERTICAL PLANES EXCLUDING THE MEDIAN PLANE.

Data in the Curves.

(*a*) Localization is most delicate at the point directly overhead. (*b*) There is an approach toward considerable accuracy in the lower quadrant near the median plane. (*c*) In addition to the fact that localization is less accurate at the side there are several conspicuous prominences situated similarly to those in the curves of the first series. Particularly illustrative of this are Figs. 13, 16, and 17.

Discussion: Introspective and Theoretical.

Localization in the Median Plane Belt. — The keenness in discrimination at the two positions above and below accords with what has been said before in regard to the localization in the belt along the median plane. The two directions are simply particular cases of that general rule. The results also agree

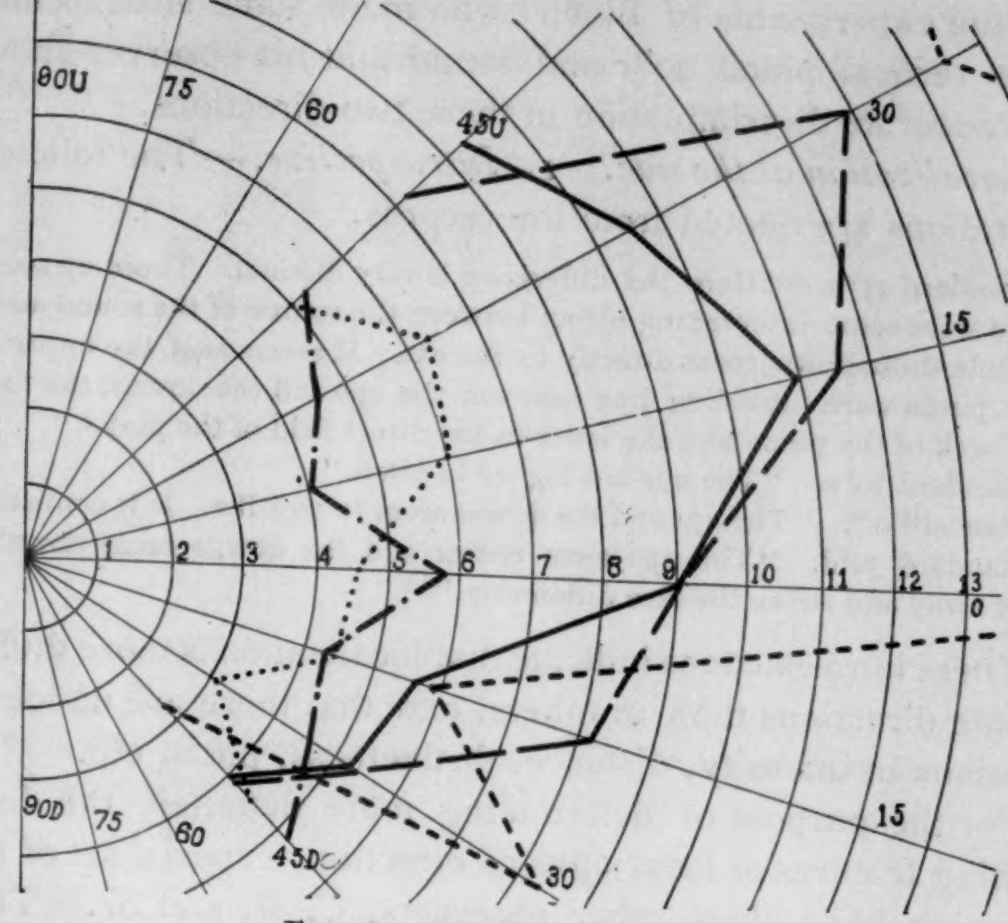


FIG. 22. Vertical plane 15°rf.

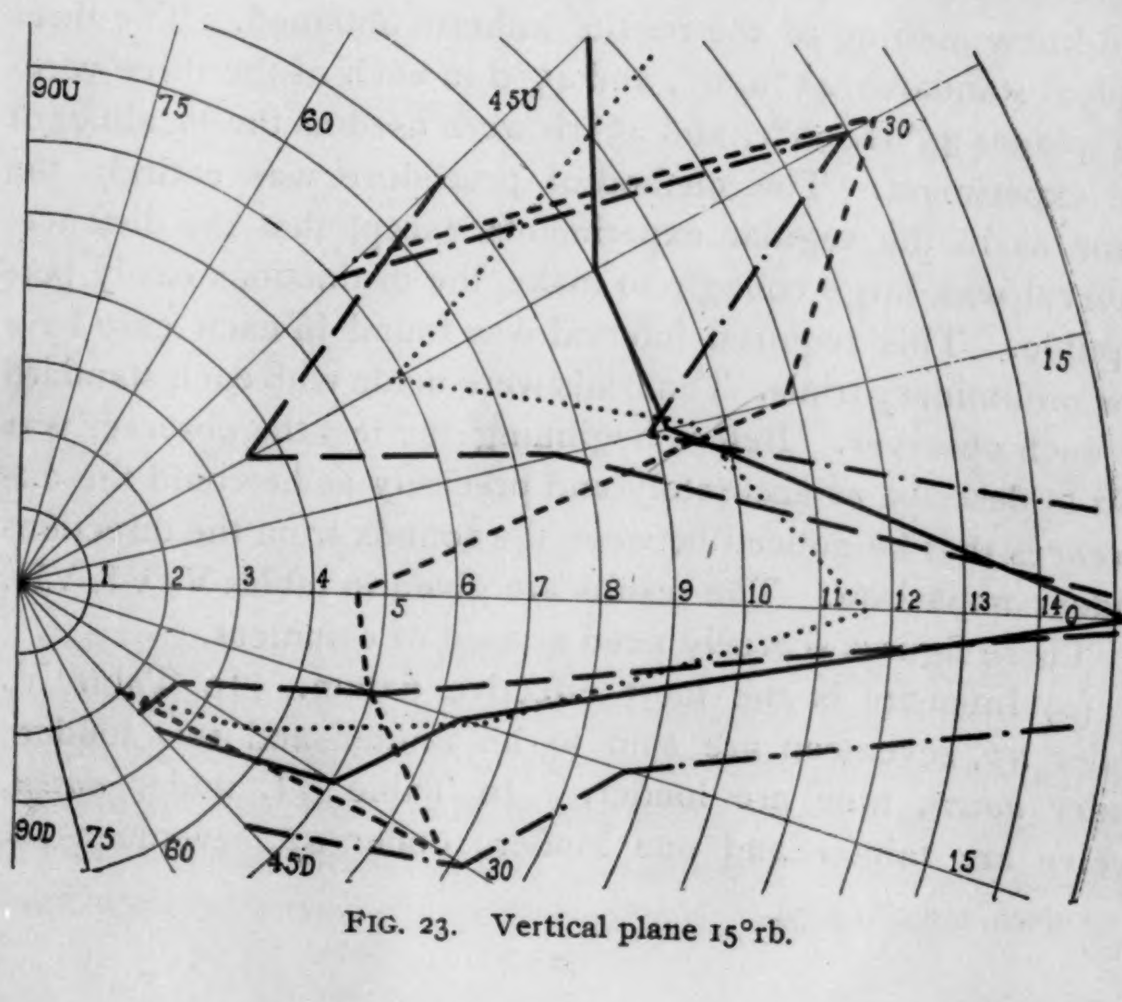


FIG. 23. Vertical plane 15°rb.

with the experiments of Bloch[1] who made some measurements in the vertical plane 90°r and found that his observer showed quite accurate discrimination in these two directions.

Localization at the side. *1. Introspective.*—The following illustrations are quoted from the records.

Standard 45°u. "Here the difference is very distinct. Those up seem as if there were some intervening object between the source of the sound and the ear, while those down come directly to the ear. It seems as if the upper edge of the pinna were a dividing line between the ups and the downs, the former being back of the pinna and the latter in the direct field of the pinna."

Standard 30°u. "The ups are higher in pitch."

Standard 0°. "The ups and the downs seem to be alike. It is confusing."

Standard 30°d. "The ups seem nearer and the downs seem down and farther away and strike the face differently."

These introspections indicate that localization is more difficult in some directions than in others, and that there are noticeable variations in intensity, distance, distinctness, pitch, etc.

For the purpose of determining more definitely the distinguishing features or local signs of direction, a special set of tests was made upon three other observers, *C*, *G*, and *Sc*. These observers had no special knowledge of the localization of sound and knew nothing of the results hitherto obtained. The three typical standards 45°u, 0°, and 45°d in each of the three vertical planes 45°rf, 90°r, and 45°rb were used as the localities of the experiment. The method of procedure was entirely the same as in the regular experiments except that the distance-interval was large enough to make the distinctions easily perceptible. This required interval was found in each case by a few preliminary trials. Ten trials were made with each standard by each observer. Before beginning the test the observer was told to describe as accurately and precisely as he could the differences that he noticed between the sounds from the directions under comparison. The results are given in tables V, VI, VII.

These figures scarcely need a word of comment.

(*a*) Intensity is the most effective datum. In Table V. under *up*, seventeen are said to be fainter and two louder; under *down*, nine are louder. In Table VI. under *down*, twelve are fainter and one louder; under *up*, seventeen are

[1] Bloch, *loc. cit.*, p. 39.

TABLE V.

THE STANDARD 45° UP IN EACH OF THE THREE PLANES.

Observers.	Planes.	Up.							Down.						
		Fainter.	Further.	Less Clear.	Pitch. h.	Pitch. l.	Thinner.	Displacement.	Louder.	Nearer.	Clearer.	Pitch. h.	Pitch. l.	Richer.	Displacement.
	45°rf	1(1)	2		2	2		3f	1	1			1		1b
C	90°r	3	2	2			1	1f	1	5			3	1·	
	45°rb				1			3b	1	1			3	1(1)	1f
	45°rf	2		2				4f	1		3		1 (?)		5b
G	90°r	3(1)	1					2f	4	3					4b
	45°rb	3	2						1	3	4				
	45°rf	1			1	2				1		1	3		4f
Sc	90°r	4	1		3	1						1	1		5b
	45°rb		1(1)		3	2				1		2	3		
		17(2)	9(1)	4	10	7	1		9	15	7	4	15	2(1)	

The figures in parenthesis are the numbers of judgment of the opposite sort to those in the column under which they occur.

TABLE VI.

STANDARDS 45° DOWN IN EACH OF THE THREE PLANES.

Observers.	Planes.	Down.							Up.						
		Fainter.	Further.	Less Clear.	Pitch. h.	Pitch. l.	Thinner.	Displacement.	Louder.	Nearer.	Clearer.	Pitch. h.	Pitch. l.	Richer.	Displacement.
	45°rf					1			2	2	1	1			4b
C	90°r		1(3)	1		2			1	(1)		1			
	45°rb	1	2	1	1	3		1b	2	1			2		1f
	45°rf	3	2					1f 1b	4		1				1f
G	90°r	3	2					4b	3			1			3f
	45°rb	2(1)	4					·2b	4	1					3f
	45°rf	2	1		3	2		3f			1		3		2f 2b
Sc	90°r	1	4			4		2f 1b		(2)		3	1		1f
	45°rb		3			5		1f	1	1		1	1		3f
		12(1)	19(3)	2	4	17			17	5(3)	3	7	7		

louder. In Table V. (standard 45°u) *up* means farther and *down* means nearer with respect to the aural axis and in Table VI. (standard 45°d) *down* means farther and *up* means nearer. Consequently the statement seems to be warranted here also, that, in the immediate vicinity of the aural axis, the nearer a sound is to the axis the stronger it seems, and *vice versa*.

Table VII.

Standards 0° in Each of the Three Planes.

Observers.	Planes.	Up. Intensity. m.	l.	Distance. m.	l.	Clearness. m.	l.	Pitch. h.	l.	Richness m.l.	Displacement.	Down. Intensity. m.	l.	Distance. m.	l.	Clearness. m.	l.	Pitch. h.	l.	Richness. m.l.	Displacement.
	45°rf				2	1		1			1f	3			2						2f
C	90°r			1			1	2	1									1	3		
	45°rb		1		2			2		1	1f		1	1					2		2b
	45°rf		3	1			1				2b		4				2				1f 1b
G	90°r	1		1				1			1b	2			2				1		
	45°rb	1	2									1	2								3f
	45°rf	1			2	2					1f	3			2	1		2	1		1f
Sc	90°r		3			1	1	1	2				3		2				5		
	45°rb	1						1	2		3b 1f							1	3		2f
		4	9	3	6	4	3	8	5	1		9	10	1	8	1	2	4	15		

(*b*) The second element in importance is distance which we may assume to be intensity in other terms and accordingly the same statement applies.

(*c*) Clearness and richness of sound are less conspicuous but nevertheless very decisive factors.

(*d*) The effect of pitch is somewhat obscure. To begin with, the results are not so definitely inclined toward one or the other side. The most general statement that is allowed is that a sound higher in position seems higher in pitch and one lower in position seems lower in pitch irrespective of the aural axis. It would seem that the difference is rather apparent than real and that the coincidence of higher and lower positions with the names, higher and lower pitch respectively, may be a matter of association or suggestion.

(*e*) Misplacements are quite frequent. They are of two kinds, forward and backward, which renders them intelligible. Let us suppose that a sound in the upper front quadrant below its standard seems backward and the one above this standard seems forward. It is reasonable to interpret these misplacements in terms of intensity and distance since the downward sound would appear louder and hence nearer, but knowledge of the positions of the sounds would unconsciously forbid the misplacement to be nearer in a radial direction toward the head.

In a similar manner the upward sound seems fainter and hence forward, *i. e.*, farther away. Some of these misplacements may occur for other reasons such as, anticipation, slight subjective or objective changes, etc.

In Table VII., where the standards are at 0°, *i. e.*, on level with the ears, the figures are indecisive and sometimes apparently contradictory. Under the column *up*, four are louder and nine fainter; under *down*, nine are stronger and ten weaker. Altogether thirteen are louder and nineteen fainter. It might be said that since the standard is nearer the aural axis than either the *ups* or *downs*, all should seem weaker. But it must be remembered that the subjective aural axis is not in the same position for all individuals. However, it is also possible that the observer may pay more attention to the second stimulus (*i. e.*, an *up* or a *down*) than to the first stimulus (*i. e.*, the standard) because he knows the position of the standard and the *up* or the *down* is the one to be determined.

If the second stimulus receives more attention it may induce the tendency to perceive it as louder. But this can scarcely impair the validity of these tables because they are quite decisive in view of this possible condition.

2. *Theoretical.* — Both the introspections and the curves present very much the same general features in the vertical as in the horizontal measurements. The factors of intensity, distance, quality, etc., and accordingly the transitions and the variations in the basis of discrimination play practically the same rôle in the vertical planes as in the horizontal planes. In these respects there seems to be no essential modification caused by the tilting of the horizontal plane through an angle of 90° to make it vertical.

On the other hand, Bloch found that his observer localized more accurately in the aural axis than at the other surrounding standards. But do we not meet similar conditions in passing from the point overhead to the axis as in passing from the front to the axis? Why should localization be more accurate relatively, in the aural axis, in the vertical measurements, than in horizontal measurements?

Comparing the upper and the lower quadrants, there is a

difference between the two in the absorption and reflection of sound by the clothes and body in the lower quadrant.

Comparing the composite curve of the vertical plane 90°r with the composite of the horizontal plane through the aural axis, we notice that the delicacy at the points above and below in the vertical plane is practically the same as at front and back in the horizontal plane. But at the other points localization is not so keen in the vertical as in the horizontal planes.

B. The Median Plane.

Median plane localization has long been known as least developed. Professor Seashore[1] found that, after all judg-

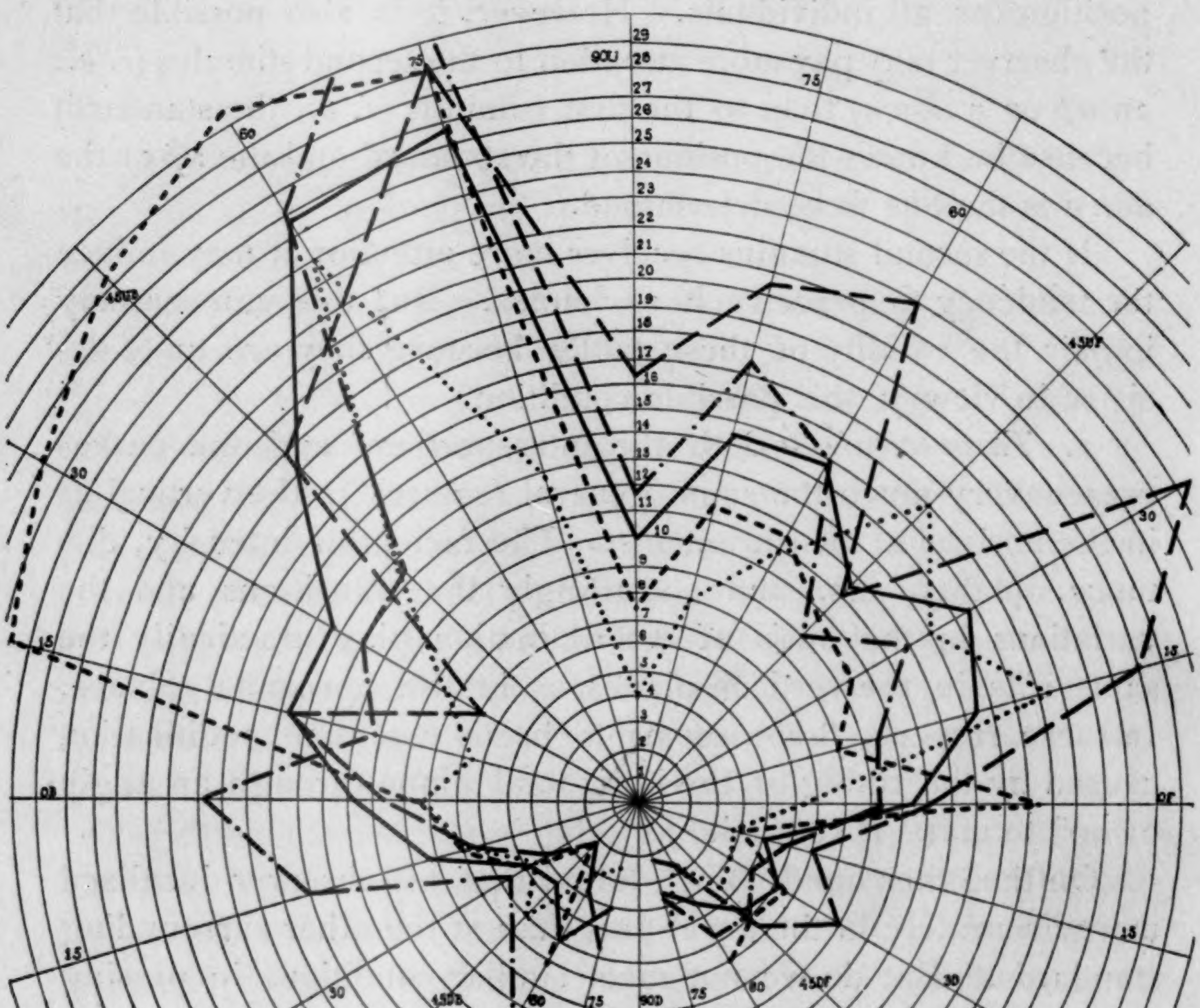


Fig. 24. Median plane.

ments correct by chance were deducted, there is a residual of eight per cent. and the implication is made that unfamiliar sounds

[1] *Univ. of Iowa Studies in Psych.*, 1900, II., pp. 46-54.

in the median plane are localized correctly only as often as chance requires.

But the conditions are somewhat different in these experiments where the sound is familiar to the observer and where the locality in which it is expected, is known so that there is almost surprising ability in median plane localization.

The Curve.—(*a*) Discrimination is more accurate in the anterior than in the posterior half, and in the lower than in the upper half. (*b*) The points of relatively accurate localization are 90°u, 45°uf, 15°df–75°df, and 45°db.

Introspective.—To illustrate the process of localization we quote again from the records.

Standard 90°u. "The standard seemed to be at 60°uf. The fronts sounded to the right and the backs to the left. This distinction seemed simply chance."

Standard 90°u. Another observer. "The fronts seem stronger."

Standard 75°uf. "The ups seemed left and the downs right."

Standard 75°uf. "The ups seem richer and closer than the downs."

Standard 60°uf. "The standard seemed to be only 35° up instead of 60°. The ups sounded just a little up and to the right. The downs seemed exactly the same as the standard, only nearer."

Standards 60°uf, 45°uf, and 30°uf. "The downs seemed richer and nearer than the ups."

Standards 45°uf and 30°uf. "The ups seemed to the right and farther away and the downs seemed to the left and nearer."

Standard 15°uf and all standards below that. "The ups seemed richer and nearer than the downs."

Standard 30°df. "The downs seemed farther away."

Standard 45°df. "All sounds seemed back of me. There was a slight difference between the ups and the downs."

Standard 60°df. "The standard seemed 22°db and a little nearer than it is in front. The downs seemed a little to the right."

Theoretical.—That the posterior half of the median plane is much less accurate especially in the upper quadrant can be attributed to the fact that the pinnæ are not so well adapted to receive sounds from the rear. That the lower half is more accurate than the upper half is very probably due to the modifying effect of absorption and reflection of the body of the observer.

There are some quite definite distinctions between directions in regard to richness, intensity, and distance. In the anterior half there are two localities from which sounds are perceived more correctly than from the other localities, *i. e.*, there are two

localities in which sounds seem richer and nearer. The composite curve has here two regions of more accurate perception of direction, 45°uf and 15°uf– 75°df. It seems probable that this condition is due to the pinnæ. Localization is more dependent upon the secondary factors.

These results are similar to those obtained by Bloch,[1] although the points do not coincide exactly, and his suggestion that the decreased delicacy between the two regions of more delicate discrimination is due to the tragus which hinders accurate perception, receives further support from these results. There is a rise and then a fall of the composite curve at 60°db which is probably due to the interference of the lobus and antitragus if we follow out the suggestion of Bloch.

Auditory Discrimination Ellipses.

Fig. 25 epitomizes the results of both horizontal and vertical measurements. The conception of sensory circles on the skin suggested this scheme of representing the space discrimination in the field of hearing. The figures may properly be called auditory discrimination ellipses. The vertical and the horizontal planes studied are represented by the straight lines, whose intersections represent the points used as standard directions in the experiments. This chart therefore corresponds to Fig. 2, and represents the right hemisphere in the field of hearing. The horizontal and the vertical axes of the ellipses represent the two measurements made at each point. As in sensory circles on the skin, we may imply that any axis of one of these ellipses represents the probable discrimination for points touched by that axis. Thus, in the ellipse at 90°r, plane 0, the horizontal axis represents 4.5°, the vertical axis 8°, and the axis with an inclination of 45° represents approximately 6.5°. This chart, then, exhibits all the numerical results of the two leading series of experiment in a graphic way.

General Observations.

1. Some additional observations were made which are either on accompanying phenomena or possible data for localization.

(*a*) Visual imagery of the position of sounds was very prom-

[1] *Bloch, loc. cit.*, p. 42.

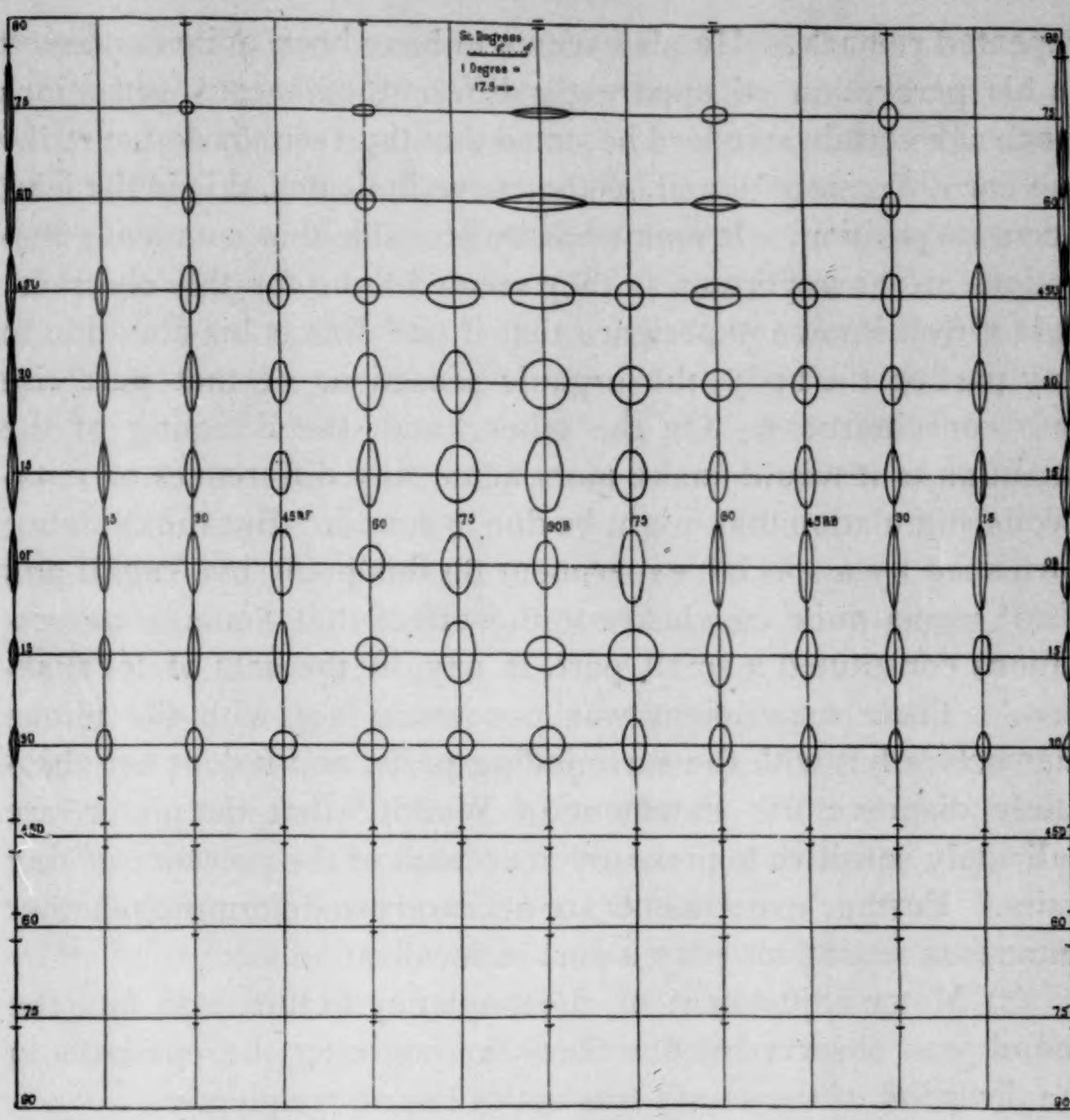


FIG. 25.

inent in the judgments of all observers. Very frequently they were conscious of scarcely anything beyond visualization. If the standard was visualized in another than its true position it was at times disturbing. This was most noticeable in the horizontal planes 60° and 75° above the aural axis, where a standard could be imagined as located in any position overhead.[1] Münsterberg[2] also found that if the observer fixated his attention upon a certain point misplacements were made that did not occur otherwise.

(*b*) With one observer tactual sensations were apparently a subsidiary means of distinguishing directions. 'Sounds from different directions strike the pinna differently' was the often

[1] Angell, *loc. cit.*, p. 14.
[2] *Loc. cit.*, p. 470.

repeated remark. He also seems to have been quite consistent in his perception of apparently different cutaneous sensations since at a certain standard he stated that the 'sounds do not strike the ear differently'; and, as the curve indicates, this is the least accurate position. It seems hardly probable that cutaneous sensations are as important as they seemed to be for this observer. It is a well known experience that if one directs his attention to any part of the body, the organic sensations of that part rise into consciousness. On the other hand, the directing of the attention to it would make more acute any differences of cutaneous stimulation that might be due to sound. But the evidence furnished by a special experiment on this point by Angell and Fite[1] seems quite conclusive to the effect that 'cutaneous sensations constituted a small part, if any, in the data of localization.' Their experiment was concerned not with the pinnæ themselves but with the surrounding parts, and it does not absolutely disprove the statement of Wundt,[2] that the pinnæ are delicately sensitive to pressure on account of the presence of tiny hairs. Further experiments are necessary to determine whether cutaneous sensations play a part in localization.

(*c*) Motor adjustment or the tendency to turn and face the sound was observed a few times, and turning the eye-balls in the direction of the sound was noticed more frequently.

2. A few very striking misplacements occurred which can be described by quoting from the records.

Vertical plane 15°rb. Standard 30°u. "The standard seemed to be 50°rf, 20°u, and eighteen inches away from the head. The ups were 15°rf, 60°u, and four feet away. The downs were 15°rf, 30°u, and one foot away." This misplacement occurred only three or four times and was especially conspicuous with one observer. In each case it was noticed in the same locality, *i. e.*, in the rear quadrant. A similar misplacement was found in the median plane.

Standard 45°ub. "The standard seemed 60°lf, 15°u, and two feet away. The ups seemed 45°lf, 45°u. The downs seemed straight back on level with the ears and a little nearer than they actually are."

Standard 30°ub. "The standard seemed to be at 60°lf, 15°u, and two feet away. The ups seemed 20°lf, 60°u, and six feet away. The downs seemed just back of the head and a little to the left."

3. After all the trials at a certain standard had been made,

[1] *Loc. cit.*, p. 236.

[2] *Physiologische Psychologie* (5th ed.), II., p. 487.

it was noticed that nearly all trials were errors. The experimenter then wanted to take a larger step, but this proved a surprise to the observer, because he had felt quite certain of his localizations and thought that he had made only a few errors. It was then suggested that he had probably reversed his process of localization for some unknown reason. The same interval was then tried again, but the observer always answered the opposite from what the direction seemed to be, for example, if a sound seemed above the standard he called it below. It was then found that he made only a few errors with the same interval. This occurred with only two observers and at the following standards: V. plane 60°rf, St. 15°u; V. plane 30°rf, St. 60°u; V. plane 60°rb, St. 15°u and St. 30°u; V. plane 45°rb, St. 0°; V. plane 30°rb, St. 60°u.

4. Comparing the first section of the double fatigue order with the second there is some improvement in the perception of direction, especially in the median plane. Pierce[1] has demonstrated that median plane localization is subject to much improvement. He concludes that 'if the exigencies of life required, an ability to locate sounds perfectly [*sic!*] within the median plane could be acquired.' The prediction of v. Kries[2] who said that, median plane localization may be possible 'wenn so zu sagen bereits erlernt ist, wie er [the sound] von vorn her und wie er von hinten her klingt' is fully verified.

5. After a large number of stimuli had been given on the right side in passing, for instance, from front to back it was very frequently observed that in testing the last point, 0°b, the standard seemed 10° or 15° toward the left instead of directly back and the sound on the left seemed much farther to the left than the one on the right seemed to the right. This was common to all four of the regular observers. Whether this is a characteristic of attention or a result of greater fatigue of the right ear is not certain. Professor Angell[3] mentions similar misplacements toward the unfatigued ear. Münsterberg and

[1] *Loc. cit.*, p. 103.

[2] Ueber das Erkennen der Schallrichtung,' *Zeitsch. f. Psych. und Physiol. d. Sinn.*, 1890, I., p. 237.

[3] *Loc. cit.*, p. 10.

Pierce[1] on the other hand find that only one out of five observers misplaced sounds after one ear was unusually fatigued.

6. The four regular observers may be divided into two types. In the one type, *W* and *S*, the curves are quite near to the center while in the other type, *K* and *B*, they sweep out farther. This suggests individual differences in shape and contour of the outer ear, differences in mental characteristics, as, in the retention of auditory images, in the presence or absence of visual imagery, etc. From another point of view there are types of observers according to the prevalence of misplacements, intensity, distance, quality, etc., in localization.

7. The fact that the sound was uniform through all the experiments and the resulting familiarity of the observers with it had marked influence upon the absolute accuracy of localization, but the validity of the comparative accuracy of the different directions is not thereby impaired.

Summary.

A twofold aim was stated at the outset. In regard to the discrimination between directions, the results show that:

1. In the horizontal planes, localization is most accurate in front, nearly as accurate in the back, and least accurate at the side. In the vertical planes excluding the median plane, localization is most accurate above and below, and least accurate at the side. In the median plane, localization is less accurate than in any other plane; it is more accurate in the anterior half than in the posterior half.

2. The delicacy of localization does not decrease gradually in passing from the median plane toward the side either in the horizontal planes or in the vertical planes, exclusive of the median plane. There are five curve prominences, *i. e.*, localities of less accurate localization, in passing from front to back, or from the point overhead to the point below.

In regard to data and elementary processes, the results show that:

3. In the greater part of the field, the localization depends chiefly upon the ratio of intensities received by the two ears.

[1] *Loc. cit.*, p. 471.

4. But within a considerable area around the aural axis, the localization is almost entirely monaural; yet intensity plays an important rôle.

5. It depends also upon other quantitative and qualitative characteristics, such as, apparent variations in intensity and distance, richness, clearness, timber, pitch, etc.

6. Variations in the characteristics of sounds occur systematically. In the immediate vicinity of the subjective aural axis, sounds nearer to the axis seem louder, nearer, richer, and clearer than sounds farther away. About the middle of each quadrant, sounds seem fainter and farther away. There are changes from binaural to monaural localization, and from monaural to binaural localization. There are also variations in the data of both binaural and monaural localization.

7. Corresponding to the variations in the data of localization there are changes in the process of localization. There are five transitions, which correspond to the five curve prominences.

8. Other features are, cutaneous sensations, motor sensations, visualization, and illusions of misplacements.

PERIODICITY AND PROGRESSIVE CHANGE IN CONTINUOUS MENTAL WORK.

BY C. E. SEASHORE Ph.D., AND GRACE HELEN KENT, A.M.

This study of the fluctuations in the efficiency of continuous mental work deals with three distinct processes: sensibility, discrimination, and memory. The experiments accordingly fall into three series. The common aim in all the series was to secure records of continuous work in representative processes under satisfactory experimental conditions. The most essential of such conditions were that the processes should be natural, definite, controllable, repeatable, recordable, and relatively free from varying associations, and that the elements of the processes should be as constant as possible, even throughout long-continued repetition.[1]

Fatigue[2] was the primary object of interest and search, but that illusive yet ever intrusive factor is almost hopelessly lost in the umbrage of related processes. Our leading effort has been to secure reliable and analyzable records of work done, then to discover the actual fluctuations in such work, and eventually to trace in part the rôles played by known factors as causes of these fluctuations.[3]

SERIES I. SENSIBILITY.

Problem, Apparatus, Method, and Observers.

The experiments in this series deal with the fluctuations in auditory sensibility which result from continuous work in listening to a liminal tone. The act which constituted the work con-

[1] The writers of this article are deeply indebted to the work of Dr. Florence Brown Sherbon whose experiments on the same subject, in this laboratory, preceded the present research. Both in the planning of our experiments and in the interpretation of the results, we have used freely the knowledge gained through the earlier work.

[2] My article on 'The Experimental Study of Mental Fatigue,' PSYCH. BULL., 1904, I., 97–101, constitutes the logical introduction to this report. C. E. S.

[3] The reader may profitably turn to Part IV. and read the 'General Conclusions' first; he will then be able to read the detailed account of the experiments more critically, having the full scope of the work in view.

sisted in *determining the moments of appearance and disappearance of a tone which oscillated 'incessantly' about the threshold.* In the following discussion, one such double determination will be spoken of as a single act — the act. The work of the whole period of an experiment consisted in the continuous repetition of this simple act. The serial record of the two thresholds which were thus determined constituted the measurement.

The stimulus was a continuous tone of variable intensity, produced by a 100 v.d. electric tuning-fork, through the audiometer.

Since some idea of the construction of the audiometer is necessary for the understanding of this report, we herewith insert, for the convenience of the reader, some extracts from the original description.[1]

The Audiometer.

The essential and unique feature of this apparatus consists in the method of varying and measuring the relative intensity of the sound. This is accomplished by applying the principle that, for certain given relations between the

primary and the secondary coils of an induction coil, the induced current varies directly with the number of turns of wire in the secondary coil. The complete apparatus consists of an induction coil, a battery, a galvanometer, a resistance coil, switches and a telephone receiver, all except the receiver being built into one compact and portable piece.

A dry battery is so connected that it may be thrown into the primary circuit of the induction coil by turning the left-hand switch. The galvanometer, seen through the crystal in the center, may be thrown into circuit by turning the right-hand switch. The fall of potential over the primary coil is reduced to the standard e.m.f., by varying the resistance by means of the plugs at the farther end of the chest and gauging it by the galvanometer. The resistance permits of as small variations as can be detected by the galvanometer; and the galvanometer detects smaller variations in the current than can be detected by the ear at the receiver. The lever at the near end of the chest is a key which is used for the rapid closing and opening of the primary circuit in producing the stimulus. No current is drawn except for the moment that the circuit is closed by this key. The primary coil is longer than the secondary. The latter is wound in forty sections, arranged in a series according to the number of

[1] Seashore, 'An Audiometer,' *Univ. of Iowa Stud. in Psych.*, 1898, II., 158–163.

turns of wire that each contains, as may be seen in the accompanying table. Each of these sections is so connected with the surface terminals along the scale that the spring contact on the sliding carriage throws into circuit the number of sections indicated by the numbers on the scale. Therefore, to vary the energy communicated to the receiver in this circuit, it is necessary only to move the carriage along the scale to the proper terminal. As it is most convenient to vary the stimulus in a geometric ratio according to the psycho-physic law, this principle has been taken as a guide in determining the scale of intensities of the sound. The numbers on the audiometer scale are given in the first column in the accompanying table; these indicate the corresponding number of sections involved in the secondary circuit. The second column gives the corresponding number of physical units in terms of the total number of turns of wire in circuit. The ratio of the increments in the sound is such that the forty steps in the series are, as nearly as can be determined, psychologically equal. The serial numbers on the scale are used in all readings. These measurements all refer to the strength of the current which energizes the receiver. The functional relation between the strength of current and the amplitude of vibration in the receiver is somewhat complex, but for the present purpose it may be regarded as fairly uniform.

Table of Values for the Audiometer Scale.

I.	*II.*	*I.*	*II.*	*I.*	*II.*	*I.*	*II.*	*I.*	*II.*
1	1	9	9	17	32	25	107	33	368
2	2	10	11	18	37	26	125	34	429
3	3	11	13	19	43	27	146	35	500
4	4	12	15	20	50	28	170	36	583
5	5	13	17	21	58	29	198	37	680
6	6	14	20	22	68	30	231	38	793
7	7	15	23	23	79	31	270	39	925
8	8	16	27	24	92	32	315	40	1079

I., scale on the audiometer.

II., corresponding values, *i. e.*, number of coils in the secondary circuit.

The range of the intensity of the sound is such that it is not probable that any person can hear the weakest sound and all who can hear ordinary conversation at all can hear the strongest sound. The average threshold for normal ears lies near the middle of the scale.

For certain tests by aurists and experiments in the psychological laboratory, it is desirable to have a tone instead of a click for stimulus. Provision has been made for the production of tones in the audiometer. The inside connections are so arranged that by attaching a double contact electric tuning-fork to the binding posts seen to the right, the fork may be made to interrupt the primary circuit of the audiometer and thus produce the tone of the fork in the receiver. This tone may be varied and measured in the same way as the regular stimulus.

An electric sounder in the measuring-room was connected with a light strap key held freely in the hand of the observer in the observing-room. The motor process which was necessarily involved in the act as defined above, and constituted the response of the observer, consisted in keeping the key closed when he heard the sound and open when he did not hear it.

The strength of the sound at the time of closing the key was recorded as the upper limit of the threshold and at the time of opening the key as the lower limit of the threshold. These two limits may be called, respectively, *To* and *Tu* ('threshold over and threshold under').

The intensity of the sound was varied by moving the carriage of the audiometer over the scale of psychologically equal units of difference in intensity. The experimenter was guided by a metronome in moving the carriage at the rate of one step per second. Starting at a point below the threshold, the carrier was moved upward at this uniform rate until the *To* signal indicated that the sound was heard; the direction of movement was then immediately reversed and continued at the same rate until the *Tu* signal was heard indicating that the sound had become inaudible; the direction of movement was then immediately reversed again and continued as before, thus making a continuous oscillation about the actual threshold throughout the whole experiment. It is evident, therefore, that the quality of the record depended upon the alertness of the observer and that the height, width, and uniformity of the threshold constitute relative measures of the efficiency of the observer at any given time.

Each experiment was continued two hours, which is a long period for continuous and homogeneous work, and probably long enough to bring out the normal fluctuations for any ordinary single period of work. The observer was seated as comfortably as possible in the observing room.[1] The room was dark and quiet and there was no avenue of communication except the signals described. The observing room is 12′ 2″ × 12′ 7″ × 10′ 8″. No ventilation was carried on during the experiment period, but the room was thoroughly ventilated with fresh air by an electric fan just before each experiment and the observer was alone in the room.

The experimenter had an assistant to record the readings

[1]This room is described in *Univ. of Iowa Stud. in Psych.*, 1902, III., 140. Ordinarily it is relatively sound-proof, light-proof, and jar-proof, but at the time of these experiments, there was a temporary disarrangement by which this room made contact with the main building. Therefore it was not so quiet as would have been desirable; strong sounds from the outside could penetrate faintly.

from the audiometer and to divide the record into five-minute periods. In all except experiments III. and X., a telephone receiver with a head clasp was used and tied lightly to the head of the observer with a band in order to secure constant adjustment. Other particular precautions will be discussed later.

The conditions thus briefly described comply fairly with the requirements as laid down at the outset. The act was natural — 'Hold the key down while you hear the sound.' It was definite: the only question which should arise was, 'Do I or do I not hear that particular sound' — and that was the question continually in the mind; the audibility of the sound at every moment was the element measured; the act was simple, familiar, and clear cut. It was controllable; the stimulus was under control, and ordinary disturbances were excluded. It was repeatable; the setting did not change by repetition and the progressive change in the internal nature of the act was open to analysis on the ground of known conditions.

The real work was in the cognitive process. The motor process was practically automatic; it was not wearing but, on the other hand, afforded a sense of relief from the otherwise restricted attitude.

While this positive statement of successful attainments is true in the relative sense in which we describe and control psychological conditions, the very rigidity of the conditions revealed shortcomings not otherwise noticeable, and no one can be more cognizant of these than the experimenters. Even if not expressly eliminated, such factors will be duly weighed before reaching our final conclusion.

There are two fundamental factors in a continued threshold test of this kind. One is the change in the physiological irritability of the peripheral organ and the other is change in the central power of concentration of attention. The latter would be the same for the two ears; therefore any change in the sensibility of the unused ear that may take place during the experiment is probably central. This fact suggests a simple test which would seem to be concise and crucial, but we encountered very serious obstacles in the way of controlling the conditions. Immediately before and immediately after the two-hour period,

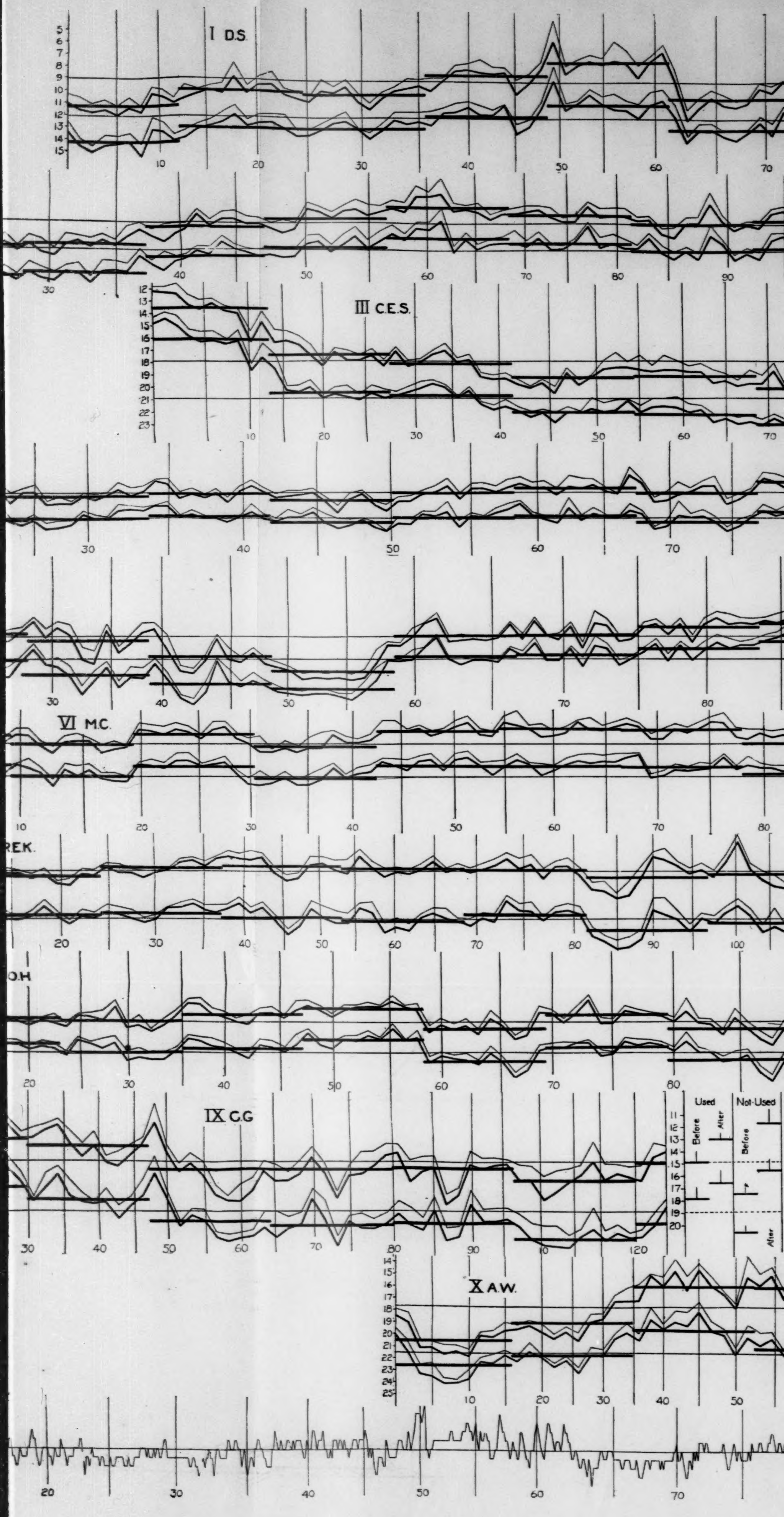
a test of twenty trials was made upon each ear, in the double fatigue order, by the same method that was followed in the main experiment. The object was to determine the threshold of each ear, under similar conditions, when rested and when fatigued.

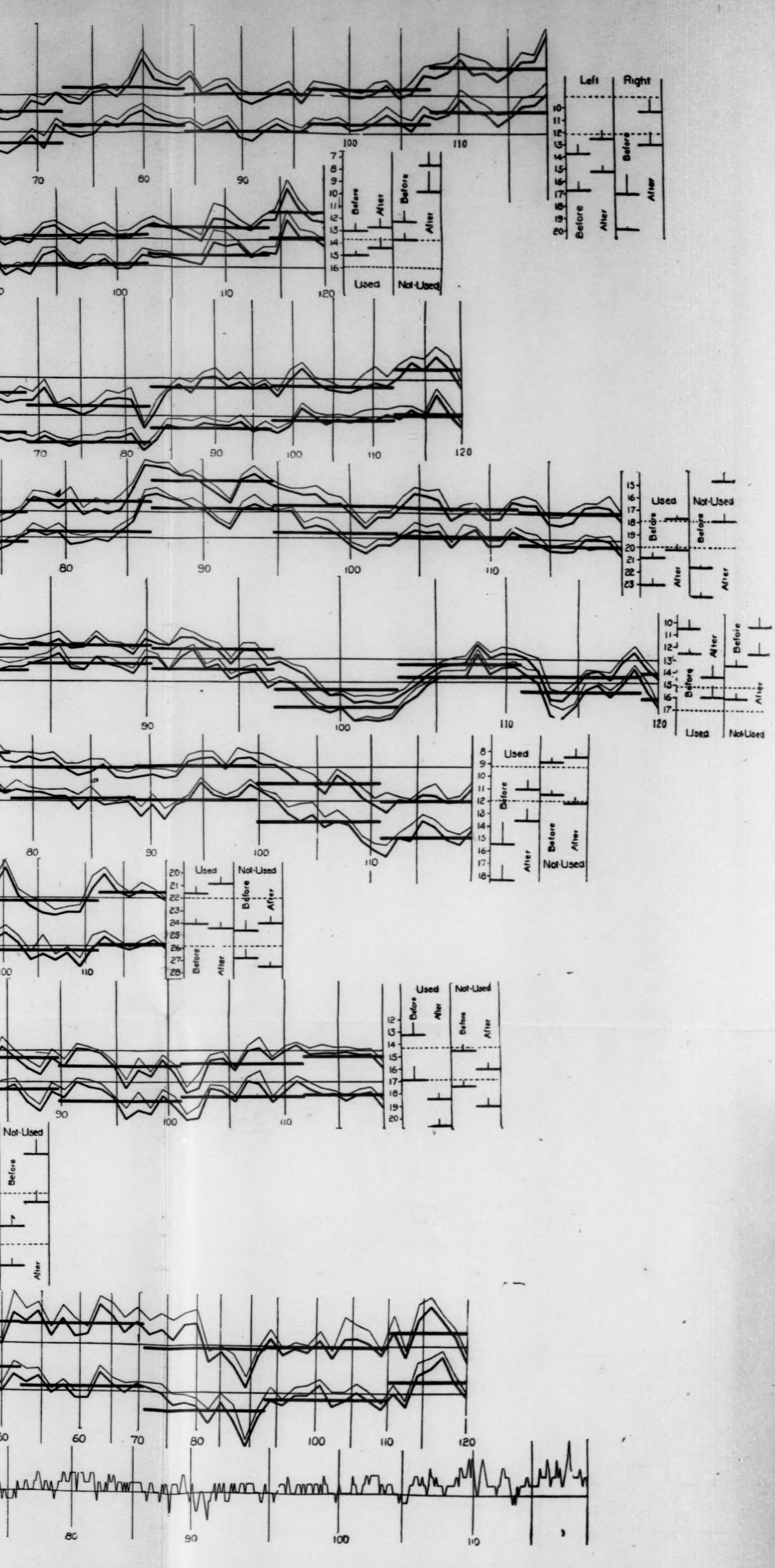
There are ten experiments in this series taken on as many observers, but all under similar conditions. The observers in experiments I., III., IV., VI., VII., VIII., and IX. are men and in experiments II., V., and X. women. These ten persons represent widely different degrees of practice, general efficiency in observing, and endurance. I. (D. S.), scholar in psychology, was thoroughly familiar with the situation and the conditions of the experiment. II. (G. H. K.), also scholar in psychology, and III. (C. E. S.) were the writers. X. (A. W.) was a first-year student in psychology, somewhat familiar with laboratory methods, but was not trained as an observer. The other observers were all students in the technical laboratory course and, with the exception of VIII. (O. H.), had had more than half a year of training as observers in the course. All knew the purpose and conditions of the experiment and took an active interest in it; but none of the observers, except the experimenters, had seen any other record of the kind.

Each observer was allowed a preliminary practice of from two to five minutes, according to need, — enough to make the requirements and the nature of the experiment clear. This small amount of practice was quite sufficient because the act was extremely simple and all, except observer X., had previously served both as observers and experimenters in the measuring of hearing ability by this very method and apparatus.

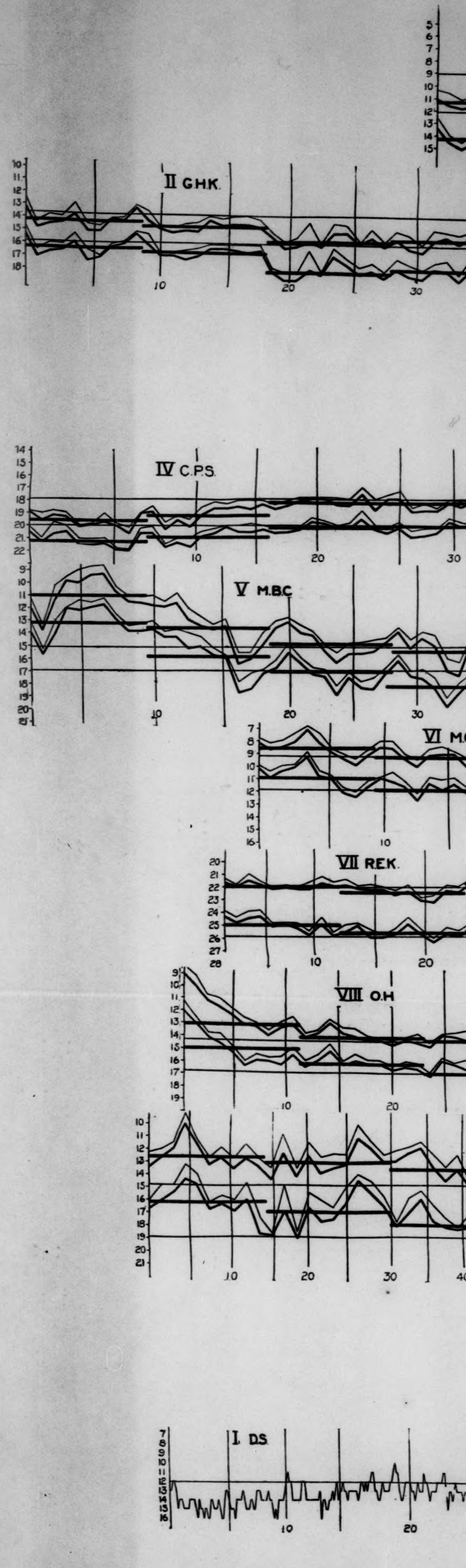
Explanation of the Records.

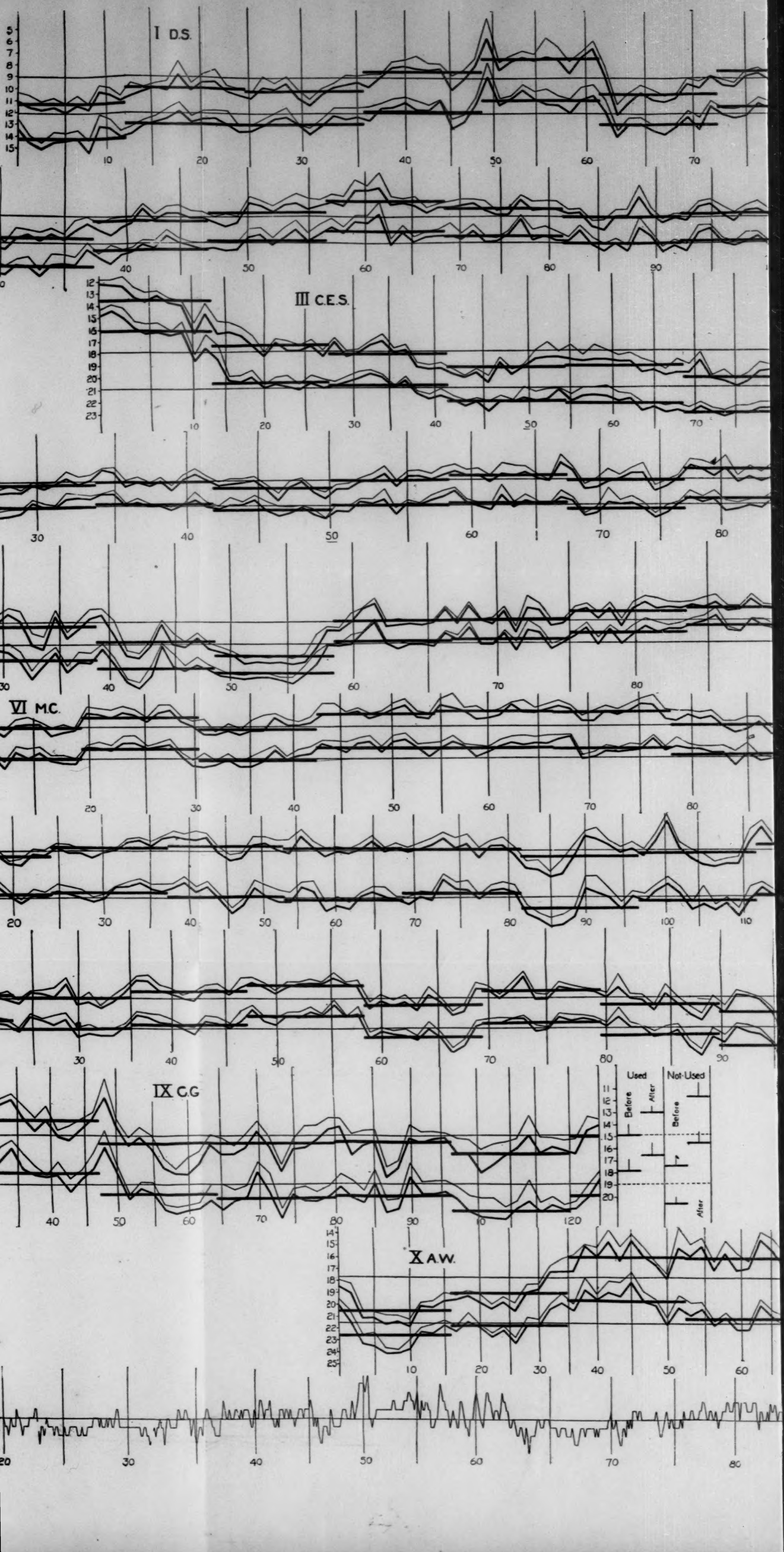
The records consist of two series of numbers representing, respectively, the successive readings for the just perceptible sound, *To*, and the just non-perceptible sound, *Tu*. The numbers of each series were averaged by tens and by hundreds, and the mean variation found for each group of ten. Instead of printing tables, we present the results in the form of curves. This method is economical and throws the results into a better single perspective than could be obtained from the tables alone.


I D.S.
III C.E.S.
VI M.C.
R.E.K.
O.H
IX C.G
X A.W.
Used
Not-Used
Before
After



Left
Right
Before
After
Used
Not-Used


II G.H.K.
IV C.P.S.
V M.B.C.
VI M.C
VII R.E.K.
VIII O.H.
I. D.S.


I D.S.
III C.E.S.
VI M.C.
IX C.G
X A.W.
Used
Not-Used
Before
After
Before
After

These curves constitute Fig's I. to X. in Plates I., II., and III. Fig. I. *a*, in Pl. I. is a representation in detail of the *To*-measurements of experiment I., Fig. I., which will be explained later.

Each of the curves represents a two-hour record of one observer. The vertical lines divide the records into five-minute sections. The light horizontal lines which extend the full length of the record show the average for the entire period, the lower being *To* and the upper *Tu*. The heavy horizontal bars mark the averages by hundreds. The heavy zigzags show the averages by tens, and the light zigzags, which are drawn on the heavy zigzags as base, show the mean variation for each of these tens. The figures at the left end give the scale of intensities in terms of the readings of the audiometer. For the purpose in hand, it is sufficient to remember that the smaller the number, the better the sensibility; so that the higher a point in the curve is, the keener sensibility it represents.

The audiometer was adjusted to different standards for different observers, in order to bring the threshold within the most convenient range of the scale; hence the absolute heights of the thresholds for different observers are not to be compared.

The observers indicated, by signals, the time of all special disturbance and had separate signals for subjective and objective disturbances. In the tabulation of the results the record of the act at such a signal was recognized only for its time-value.

The results of the before- and after-tests are represented graphically at the right end of each curve. The long average-lines of the main record are represented by dotted lines for the purpose of facilitating comparison. The horizontal lines show the average *To* and *Tu* before and after. Each is the average of twenty trials, the mean variation of which is represented by a vertical line upon the horizontal. The units in the scale of intensities are on the same scale as in the main curves.

Criteria of Change.

At least three criteria may be taken into consideration in an attempt to evaluate the efficiency of the work represented in these records. They are: (1) The height of the threshold; (2) the mean variation; and (3) the width of the threshold.

The first is self-evident: the higher the curve, the keener the sensibility. It is a quantitative measurement.

The mean variation may be large or small regardless of whether the sensibility is keen or dull. In this experiment it is probably not a measure of the sensibility of the sense organ, but of the power of concentration of attention. It is, however, a measure only so long as there is a continuous, maximum effort of concentration, which is the condition sought in these experiments. Even then it must be interpreted with great precaution and only in the light of introspective accounts.

The width of the threshold, which is the difference between *To* and *Tu*, depends upon the alertness of the observer. Slow reaction tends to give a low *To* and a high *Tu*, thus increasing the difference in both directions. A wide threshold means a long act; hence the number of acts in a given period varies inversely with the width of the threshold. The width of the threshold in records III. and X. is due in part to the method of reaction employed by the experimenter in these which were the first two experiments, but the method was uniform throughout the records. With this limitation, the characteristic width of each record is probably an expression of the personal equation of the observer. It may be assumed, other things being equal, that a narrow threshold indicates alertness, *i. e.*, steady keenness in discriminative attention. The principal counter-factor is the tendency to automatism. The automatism is at least favored by the approximate coincidence of the time of hearing with the high crest of the normal attention-wave. The feeling of 'let it go' came not only from the physical change in the stimulus but also from the termination of the subjective attention-wave. One of the writers experienced that very distinctly in the special experiment on that point (see p. 60, following).

Before we make any physiological or psychological interpretation of the records, we must inquire whether the fluctuations may not be due to changes in the stimulus. We have taken every precaution to keep it constant. The receiver on the audiometer is of good quality and well seasoned; we used the Edison-Lelande cells; the temperature was practically constant; as the interruption by the fork took place in a shunt cir-

cuit, the main circuit remained permanently closed; and the current was minimal so that there could not be serious danger from permanent self-induction. Therefore, although we have no absolute proof of the constancy of the stimulus, we must proceed on the assumption that it remained at the same standard. We may also invoke the evidences obtained in other series of experiments and especially those on sight. As will be seen, the conclusions drawn from this series on sensibility are all corroborated by the experiments in the two following series. They were also corroborated in visual experiments in which we had absolute control of the stimulus.

Periodic Change: A. Hour-waves.

The most salient feature in the records, especially with reference to the height of the threshold, is a periodicity. The records agree in showing at least two sets of rhythmical fluctuations; and, in addition to these, there enters the well known attention wave, which practically coincides with the individual acts and therefore does not appear as a wave in the record. For convenience, we may designate the three sets of waves, respectively, as

1. The hour-waves (20 to 200 minutes).
2. The minute-waves (½ to 20 minutes).
3. The second-waves (a few seconds).

The hour-wave can be seen most clearly by following the main zigzag lines showing the averages by tens. In some records two sets of hour-waves are discernible. For convenience we may call them the large and the small. The dividing line between the two groups is arbitrary and may be taken at about thirty or forty minutes.

In order to show approximately the number and length of the hour-waves a diagrammatic table, Table I., is given showing the upper and lower points, the crest and the basin, of each wave. The numbers denote the time, counting in minutes from the beginning of the test, and they are placed in an upper or a lower line according as they represent high or low points in the waves. The wave-length is proportional to the horizontal distance between the numbers, but differences in height are not

Table I.

Periods of the Hour-waves in Figs. I. to X.

I.	50, 80, 120	5, 65, 90
I.	20, 50, 80, 110, 120	5, 30, 65, 90, 115
II.	0, 60, 115	30, 90
III.	0, 115	75
III.	0, 35, 55, 100, 115	20, 45, 80, 110
IV.	35, 85	5, 60, 115
IV.	20, 35, 60, 90, 105	5, 25, 50, 75, 100, 115
V.	5, 85, 110, 120	55, 100, 115
V.	5, 20, 45, 60, 90, 110, 120	0, 15, 35, 55, 75, 100, 115
VI.	5, 25, 60, 100	15, 35, 90, 110
VII.	0, 40, 75, 100, 115	20, 60, 85, 110
VIII.	0, 55, 75, 120	30, 65, 100
IX.	5, 25, 50, 70, 90, 120	15, 40, 60, 80, 105
X.	45, 115	5, 90
X.	0, 20, 45, 65, 100, 115	10, 25, 50, 90, 110, 120

shown. In these estimates, *To* is taken as the principal guide because it is a more reliable index to the moment of perception than *Tu*; the appearance of a sound can be determined more definitely than its disappearance.

The estimates in this table are, of course, somewhat arbitrary. In many cases there is latitude for differences in interpretation. The table represents the estimates upon which the writers have agreed. In five records, (I., III., IV., V., and X.) large and small hour-waves are discernible in more or less distinct sets, as indicated in the table. II. and VIII. might also

have been divided into short waves, but these waves are not very distinct.

The waves vary not only in length but also in form. While the general tendency is an approximation to the sine curve, this form suffers all sorts of distortion. On the assumption that there are two or more sets of waves, one can readily see the effect of interference and reinforcement. But many sporadic variations seem to be due to aperiodic influences.

One very expressive feature is that there is a tendency for the hour-wave to be shorter in the latter half of the record than in the first. This may be seen on a glance at Table I. Where there are two sets of hour-waves there is a tendency for the two to coincide near the end. Compare the two sets of waves, *e. g.*, in Record I., Table I.

One might suppose that every record should begin with a high crest, but there is no constant tendency in that direction.

Periodic Changes: B. Minute-waves.

We have spoken of the main curves as zigzags. These zigzags bring out the minute-waves. In order to show these short waves more clearly than they are shown in the curves of averages, a section of the *To* from each of the ten curves is represented in detail (Pl. II.). All these sections begin with the beginning of the second half hour of the record and include two hundred acts. This portion of the record is selected because it is perhaps freest from erratic variations, coming as it does after a period of adaptation and before the onset of discomfort.

Fig. I*a*, Pl. I., represents the whole *To*-record in this manner for Record I., to which it runs parallel. It shows how the minute-waves enter as partials in the hour-waves.

The tendency toward periodicity is unmistakable, but the waves are not homogeneous, nor are they limited to one system. Here, as in the longer waves, different sets of tendencies are operative producing reinforcements, balances, or interferences. One wave appears as a partial in another and is itself made up of ripples. A minute-wave may be a partial in an hour-wave; there is a gradual transition from one to the other.

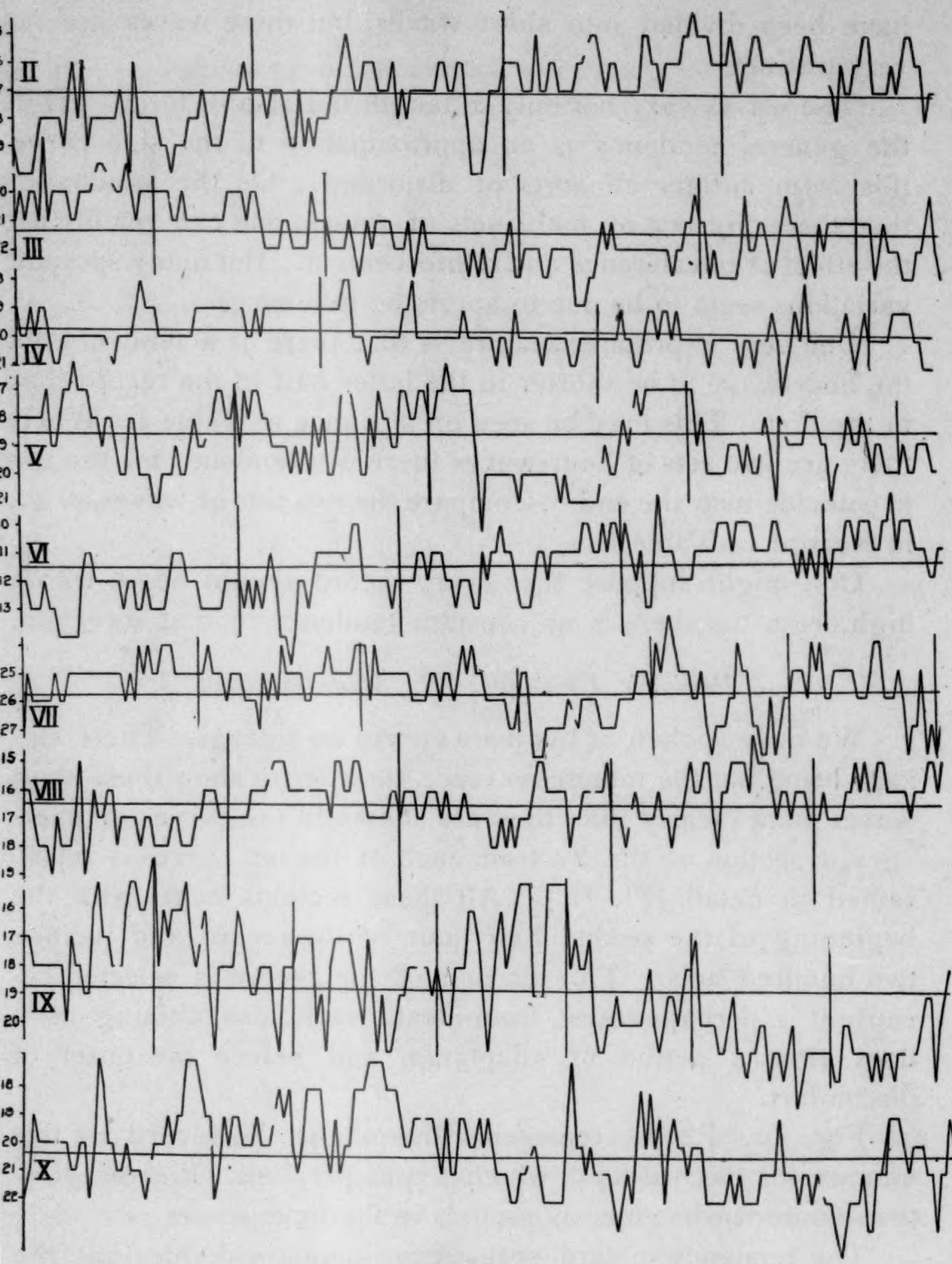


PLATE II.

Periodic Change: C. Second-waves.

The attention-wave of Urbantschitsch[1] plays an important rôle in this work. It is unnecessary to enumerate here the con-

[1] *Med. Centralbl.*, 1875, 628 ff. **Good summary accounts are found in Titchener,** ***Exp. Psych.*****, 'Instr. Man'l, Qualitative,' 194 ff., and in Wundt,** ***Physiol. Psych.*****, 5th ed., III., 366 ff.**

clusions of the valuable researches on that wave. We have assumed its existence and it remains to point out under what conditions it entered into the present process. We shall try to show that the attention-wave in this experiment is synonymous with, or rather, constitutes, what has been defined above as the second-wave.

The act which is the object of study in this series on sensibility, as defined on page 3, forms a peculiar basis for the second-wave. Owing to the method employed in recording, these waves do not show in the records, but the known conditions and requirements and the introspective accounts furnish us satisfactory evidence of their existence.

The act may be regarded as the basis for one wave or for two, according to the point of view taken. According to the former, not only is the duration of each act approximately the length of an attention-wave, and its recurrence periodic, but the stimulus constitutes a wave in its intensity change — rising from an imperceptible stimulus, through the just perceptible, to the more than just perceptible, and then back, receding to the non-perceptible. Corresponding to this, there is a complete wave of consciousness, for, on account of associated imagery, the subliminal part of the wave is as concrete in consciousness as the supra-liminal part.

According to another point of view, the act readily divides itself into two complete and distinct movements of attention, the maxima of attention being just before *To* and *Tu*, respectively, and the corresponding minima immediately after these points. The two waves in an act differ quite radically in character, but they both serve the same purpose, namely, rest through relaxation of attention. A moment of relaxation followed the perception indicated by *To* because the sound grew relatively strong during the united reaction-time of the observer and the experimenter; and, the approximate duration of this intensity was known from the preliminary practice. Then a moment of relaxation followed the perception indicated by *Tu*, from the conviction that the sound had gone below the threshold and there would be a certain appreciable time before it could return. Thus, in one case the attention relaxed for a moment because

the sound was so strong that it could be heard with ease, and in the other because the observer assumed that, for the moment, it was inaudible. Similarly the knowledge of the periodicity in the stimulus enabled the observer to concentrate attention at the probable appearance of the thresholds *To* and *Tu*.

In order to compare the work in which the second-wave is merely subjective with that in which it is also objective, Observer III. took a special test. The same apparatus was used as before but, instead of a sound varying about the threshold by actual change in intensity, the stimulus consisted of a liminal sound of constant intensity, and the observer recorded the subjective fluctuations by holding the key down while the sound was heard and free while the sound was not heard. In order to minimize the tendency to hallucination, a one-fifth second interrupter was substituted for the fork. A graphic record was taken by means of the multiple recorder.[1]

The experiment covered a period of two hours. From the facts learned in the foregoing experiments, it was evident that one intensity of sound would not remain liminal throughout that long period. Therefore we adopted the arbitrary method of raising or lowering the intensity of the sound by one step on the audiometer when the sound had been heard or not heard, respectively, for a continuous period of thirty seconds.

The experiment was made 3:17 to 5:17 p. m., April 14, '04. The introspective account follows:

> I was in fairly good condition for afternoon work. Thought that probably I had remained at the same standard all the time because I was not aware of having had any periods long enough to call for the change. The subjective standard was retained satisfactorily throughout.
>
> The wave seems to be dependent upon voluntary effort to a large extent. At times I would feel, 'now I have held it so long that I must give up in order to be able to continue.' Very many of the fluctuations are due to slight disturbances, both subjective and objective. The tendency to fall into an automatic rhythm is especially dangerous. For these reasons I do not place much significance upon the length of the waves. Yet the objective disturbances were only such as we notice when ordinary disturbances are excluded, and the rhythm is in part really what we seek.

[1] The recorder is described in *Univ. of Iowa Stud. in Psych.*, 1901, III., 1–16, as a part of the psychergograph. In its present form, fountain pens are used in place of the lead pencils, and an electric motor is used instead of the clock-work.

The heard sound varied within wide limits; at times it seemed as much as five points stronger than the barely perceptible, and I was able to notice distinct wavelike rises and falls in intensity. This experiment is more taxing on attention than the other experiments (Series I.).

Let us first observe the bearing of this special experiment upon the interpretation of the second-wave in the main experiment. Fig. 11 shows the numerical distribution of the different lengths of the attention-waves — the solid line for 'sound heard' and the dotted line for 'sound not heard.' The length is represented in seconds on the base-line and the vertical scale shows the number of cases at each level. The period for which the sound is heard most frequently is 6 seconds, and the period of greatest frequency for the sound not heard is 3 seconds. The curve rises at 30 because that point includes all that would

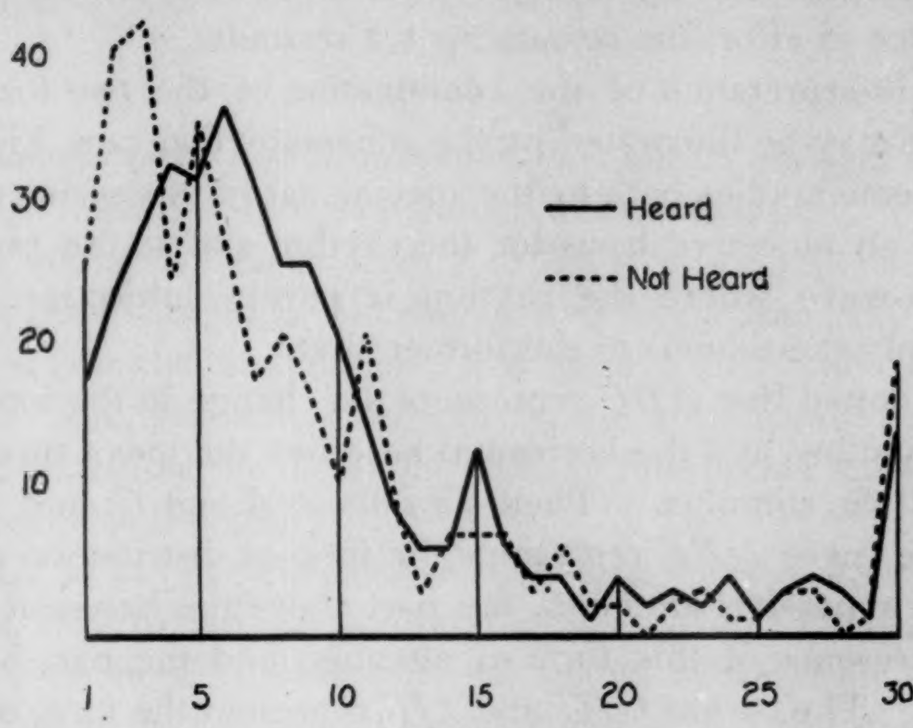


FIG. 11.

have been longer than 30 seconds if the standard had not been changed at that mark.

The most frequent length of the complete attention-wave in the special experiment is, therefore, about 9 seconds. The average duration of a complete act in the main experiment upon this observer (see Fig. III. in Plates I., II., and III.) was 8.4 seconds. That is, the typical attention-wave, purely subjective, coincides well with the objective wave in an act. In a way, the periods of supra-liminal sound correspond in the two experiments, so

that we may say with reference to both that the sound was heard during the attention-wave and not heard during the inattention wave, provided we count the threshold transition periods with the former.

This wave which coincides with the act is a wave of secondary passive (Titchener) attention.[1] Within it, we find two distinct waves of active attention. Such is the case both in the experiments in this series and in the classical experiments upon the attention-wave.

Since the average length of the act was 8.4 seconds for Obs. III., the length of each active attention-wave was about half of that, or 4.2 seconds, in accordance with the conditions of the experiment. It is safe to estimate that the period of effort occupied about 3 seconds out of the total, and the period of absence of effort the remaining 1.2 seconds.

The interpretation of the combination of the two forms of attention may be illustrated by the schematic diagram, Fig. 12. The scheme applies both to the special act in this series where there is an objective basis for the rhythm and to the familiar attention-wave where the rhythm is purely subjective. We shall apply the scheme to the former first.

The dotted line *ABC* represents the change in the intensity of the stimulus, and the horizontal base-line the mean threshold value of the stimulus. Then *To* falls at *A* and *C*, and *Tu* at *B*. The curve *DEF* represents the form of distribution of the secondary passive attention, the part above the base-line indicating presence of this form of attention and the part below, absence. The curves *GHI* and *IJR* represent the form of distribution of the active attention-waves.[2]

The figure thus throws into clear perspective the result of the analysis of the complete attention-wave into its two component elements and suggests the general outline of the resultant of the two. There is a state of attention from *G* to *E*, but it differs in kind and strength, and the wave is not smooth, as

[1] For brevity, it will be spoken of hereafter as the passive, with the understanding that the *secondary* passive is meant.

[2] To coincide with the act as described in the main experiment, this diagram should really begin at *I* and make a complete cycle from that point instead of from *G*. No account is taken of the difference in the level of *To* and *Tu*.

has been supposed; it has three distinct prominences. The crests of the waves *GH* and *IJ* are the result of special effort, while the longer crest in *DE* represents no effort and yet a state of clear attention. But the three elevations are parts of a single phase of a long wave *GE*, because the attention is continuous during that period.

The period of inattention is short — only from *E* to *R*. But the period of absence of active attention does not coincide with the period of passive attention; they change off in part, as it were. The former runs from *J* to *R* and the latter from *E* to

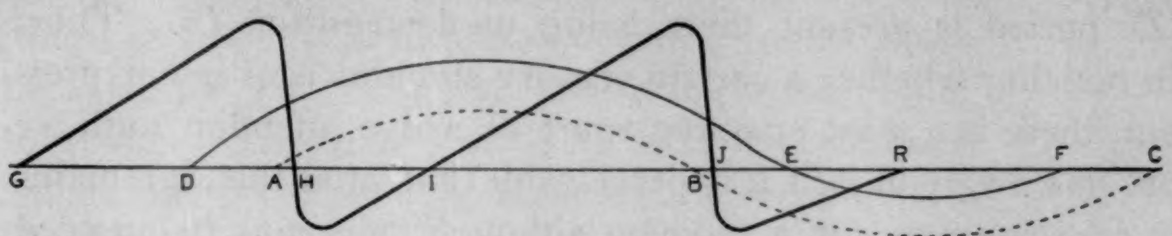


FIG. 12.

F. Therefore the rest from attention is not of uniform nature, any more than the attention was of uniform nature. From *B* to *C* no sound is heard; from *J* to *E* there is complete rest as regards active attention, but the passive lags; from *E* to *R* is a period of complete inattention; and from *R* to *F* only the passive attention is absent. Of course, the significance of these differences below the threshold must be interpreted in terms of the subconscious states.

Now, as has been suggested, the same analysis applies in a general way to the subjective attention-wave. To apply the scheme, we need to omit only the dotted curve, which represents change in the stimulus, and suppose that the stimulus is constant. The combination of the active and the passive attention-wave follows the same principle here as where the change is objective. It is easy to observe in the attention-wave experiment how the effort is exerted only at the point of coming in and the point of going out of the sensation; between these points the sensation holds the sway of consciousness and the clearness of the sensation during the middle period is in no way proportional to the effort of attention.

Have we not here discovered one of the secrets of endurance, a principle of economy and efficiency which applies to

all mental activity? Are not the two experiments here discussed — the one in which the change is objective and the one in which the change is only subjective — fundmental types of attentive consciousness? This most elementary periodicity is not peculiar to continuous work under pressure. It is a characteristic of the ordinary mental activity even if there be only a single act of a few seconds duration.

Observe its working in simple observation, sensory or logical pursuit, constructive imagination, reasoning, etc. — processes which require attention. Frequently, however, only the *To* period is present, there being no demand for *Tu*. Thus, in noticing whether a certain sensory stimulus is or is not present, there is a most effective spurt of active attention until we become aware of it (if it is perceivable) but, after that, it remains in consciousness for a moment although there may be no need of it, and there has been no objective strengthening of the stimulus. This is true not only of liminal stimuli but of stimuli of any strength which need to be selected by an effort of attention. The effort which lands the impression in consciousness is momentary and intense but the continuation of the impression in consciousness in its original, or even increasing clearness, is due to an after-beat, a pulsation of the secondary passive attention-wave.

The longer waves in this special experiment also deserve a passing notice. Fig. 13 represents the changes made in the standard during the two-hour period according to the prearrangement mentioned above. It is a crude way of representing the minute-waves and the hour-waves. The numbers at the left refer to the audiometer scale; and those at the base denote the time in minutes. A comparison of this figure with Fig. III. in Pl. I. and III. reveals a striking agreement of the two records. It is especially noticeable in the long hour-wave which starts with a high crest and then spreads over a long basin and finally rises again. This demonstration of the hour-waves proves that they are not peculiar to the kind of work done in the main experiment.

Progressive Change.

Next to the periodic change in these records, our interest centers on the question of progressive change. For the purpose of demonstrating any progressive tendencies which may be present in the record as a whole, the results of the two halves of each record are arranged for comparison in Table II.

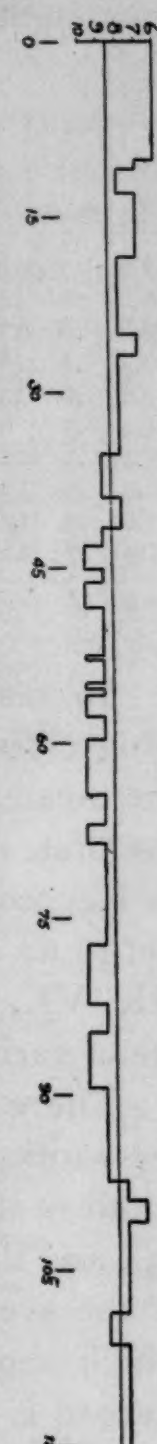


FIG. 13.

The first column shows the average *To* for the first half of each record, and the second shows the average mean variation of these on the basis of groups of ten. The third and fourth columns show the same for *Tu*. The fifth shows the width of the threshold — *To* minus *Tu*. The next five columns contain the corresponding facts for the second half. The eleventh and the twelfth columns give the differences between the two halves, the plus sign indicating loss and the minus sign gain in sensibility. The thirteenth column shows the difference in the width of the threshold for the two halves. The fourteenth shows the range of variation in *To*, *i. e.*, the difference between the highest and the lowest points in a record on the basis of one hundred acts as a unit. The fifteenth column shows the range of variation in the width of the threshold on the same basis.

In respect to sensibility, or height of the threshold (Col's 11, 12), the records may be divided into three classes: those which indicate gain (I., II., IV.); those which indicate loss (VI., VII., VIII., IX.); and, those which indicate no decided gain or loss in sensibility (V., X.). For fuller interpretation, the form of each curve should be taken into consideration. In Record III., *e. g.*, there is a progressive loss during the first two thirds of the period and a gain in the last third. It is certain that there is no general tendency in favor of loss or gain. The .5 (Col. 11) balance in favor of loss in *To* is only twelve per cent. of the range of variation in *To* (Col. 15) and is negligible; the corresponding balance in *Tu* is only .1. To what extent we may regard the records as revealing types of observers, remains to be demonstrated.

Table II.

Comparison of the First and the Second Half.

	First half.					Second half.					*To* 2d half minus *To* 1st half.	*Tu* 2d half minus *Tu* 1st half.	Width 2d half minus Width 1st half.	Range of var. of *To*.	Range of var. in Thr. Width
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Exp.	*To*	*m. v.*	*Tu*	*m. v.*	width	*To*	*m. v.*	*Tu*	*m. v.*	width					
I.	12.6	.7	9.5	.7	3.1	11.6	.6	8.7	.6	2.9	—1.0	— .8	— .2	3.9	.9
II.	16.8	.6	14.6	.6	2.2	15.1	.6	12.8	.6	2.3	—1.7	—1.8	+ .1	4.5	.5
III.	19.8	.6	17.1	.6	2.7	21.8	.5	18.7	.7	3.1	+2.0	+1.6	+ .4	6.9	1.1
IV.	20.3	.4	18.5	.4	1.8	19.6	.4	17.3	.5	2.3	— .7	—1.2	+ .5	3.6	1.1
V.	17.1	.6	14.9	.6	2.2	16.7	.4	15.3	.5	1.4	— .4	+ .4	— .8	6.2	1.7
VI.	11.4	.5	8.8	.5	2.6	12.3	.6	9.5	.7	2.8	+ .9	+ .7	+ .2	3.9	.8
VII.	25.4	.5	21.9	.4	3.5	26.1	.6	22.0	.7	4.1	+ .7	+ .1	+ .6	1.9	1.3
VIII.	16.0	.5	13.6	.4	2.4	17.6	.5	14.8	.4	2.8	+1.6	+1.2	+ .4	3.3	1.1
IX.	17.6	.9	13.8	.9	3.8	20.4	1.0	15.7	1.1	4.7	+2.8	+1.9	+ .9	4.9	1.3
X.	21.3	.7	18.5	.7	2.8	21.7	.7	17.1	.9	4.6	+ .4	—1.4	+1.8	3.2	3.1
Ave.	17.8	.6	15.1	.6	2.7	18.3	.6	15.2	.7	3.1	+ .5	+ .1	+ .4	4.2	1.3

In respect to mean variation there is still less evidence of progressive change (Col's 2, 7; 4, 9). In Records I. and V., the mean variation is slightly smaller in the second half than in the first, *i. e.*, the records tend to improve in regularity; and, in Records IV., VII. and IX., it is larger in the second half, but in no case is the difference very great. In five records (I., III., VI., VIII., X.), and in the average for the ten records the mean variation is practically equal for the two halves.

There is a more decided progressive tendency in respect to the width of the threshold. Eight records show an increase in width in the second half as compared with the first (Col's 5, 10, 13), and the average increase is .4, which is thirty-one per cent. of the average variation in width (Col. 15). In the two records which show a decrease in width, the change is very small in Record I. and, in Record V., it is partially explained by the introspective record.[1]

[1] According to the introspective account the exceptionally large increase of width in Record X. is accounted for in part as due to a change of standard of certainty. The uniformity in Record II. is due in part to a conscious effort to avoid the widening of the threshold.

Correlation of Changes.

In retrospect, we may review the three kinds of changes with reference to periodic changes, progressive changes, and the correlations of the three factors, by means of the juxtapositions drawn in bold outline in Pl. III. and the table of correlations, Table III.

Pl. III. contains outline reproductions of the ten records. The curves are drawn on the basis of averages for one hundred acts for each point and represent *To*, *m. v.*, and threshold width. For the present purpose, *Tu* would be similar to *To* which is used. The *m. v.* here used is the mean between the

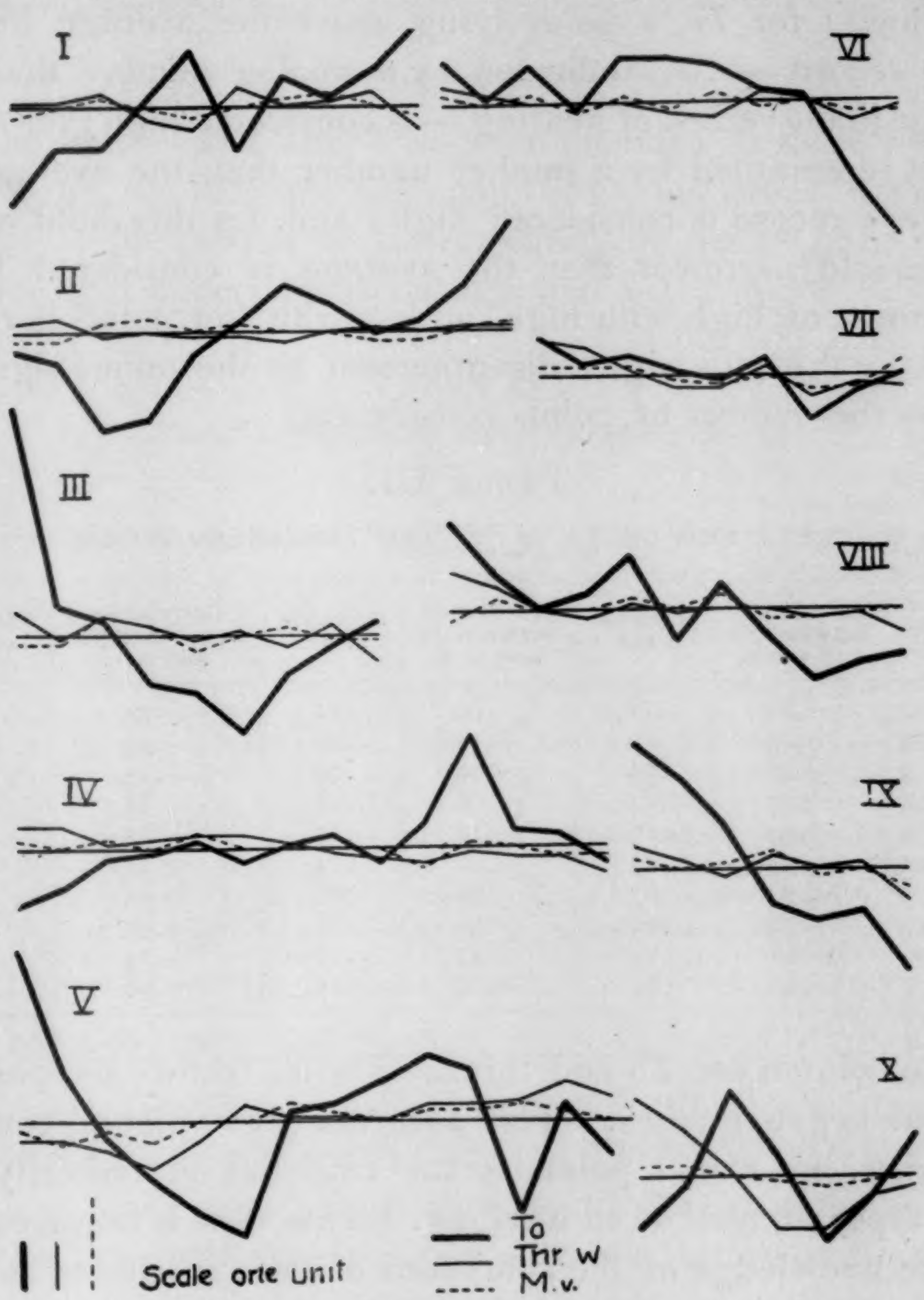


PLATE III.

average mean variation for *To* and the average mean variation for *Tu*. The ordinate scale is twice as large for the *m. v.* as for the other two curves. The horizontal line is a common base and represents the averages of the respective factors for the whole record.

The same data on which the figures in Pl. III. are based are treated by Pearson's formula of correlations. The results are presented in Table III.

For the purpose of this correlation, a point — *i. e.*, the average of one hundred acts, following the grouping indicated by the heavy horizontal bars in Pl. I. — is considered high or low as follows: for *To*, a point lying above the average for the whole record — *i. e.*, indicated by a smaller number than the average in the record of hearing — is considered high; for *m. v.*, a point represented by a smaller number than the average for the whole record is considered high; and, for threshold width, a threshold narrower than the average is considered high. Agreement of high with high, or low with low points is represented by the plus sign; disagreement by the minus sign. *n* denotes the number of points considered.

TABLE III.

CORRELATIONS OF *To*, *m. v.*, AND THRESHOLD WIDTH.

	n.	Correlation between *To* and width.	Probable error.	Correlation between *To* and *m. v.*	Probable error.	Correlation between width and *m. v.*	Probable error.
I.	10	—.64	.11	—.09	.21	+.54	.13
II.	12	+.05	.19	+.12	.19	+.49	.13
III.	9	+.40	.15	—.26	.20	+.25	.20
IV.	14	—.37	.14	—.06	.18	+.65	.09
V.	14	—.04	.18	—.12	.17	+.75	.06
VI.	11	+.31	.17	+.60	.11	+.34	.17
VII.	9	+.79	.07	+.86	.06	+.55	.14
VIII.	11	+.79	.06	+.36	.17	+.02	.20
IX.	7	+.62	.13	+.47	.18	+.79	.07
X.	7	—.10	.25	+.04	.25	+.90	.04

The column for *To* and threshold width shows six positive and four negative cases. This does not prove that no correlation exists, but rather points to the existence of radically different types of method in working. This view is borne out by intimate knowledge of the conditions of the experiment and by the introspective observations.

The columns for *To* and *m. v.* show a similar divergence, although there is a stronger preponderance in favor of a positive correlation.

There is a strong correlation between the *m. v.* and the threshold width. This probably means that *m. v.* (variability) and width (alertness) are signs of the same general central efficiency. If the *To* (sensibility), had remained constant in the record of a period, the decline in the central process would indicate that there was an increase in the peripheral efficiency. But in view of the conflicting types of the records we dare not draw the conclusion that there is a progressive increase in peripheral sensitiveness.

'*Before*'- and '*After*'-*Tests.*

The before- and after-tests were intended to show what effect, if any, the long test had upon the ear not used. A marked change in the relation of the sensibility of the two ears would indicate that a peripheral change had taken place in the ear used.

TABLE IV.

THE 'AFTER'- AND THE 'BEFORE'-TESTS.

	After as Compared with Before.				Ear Used as Compared with Average of Long Test.				Before-Test. Ear Used, as Compared with First 100 Reactions of Long Test.		After-Test. Ear Used, as Compared with Last 100 Reactions of Long Test.	
	Ear Used.		Ear not Used.		Before.		After.					
	To	*Tu*	*To*	*Tu*	*To*	*Tu*	*To*	*Tu*	*To*	*Tu*	*To*	*Tu*
I.	−10.0	−10.3	−4.6	−4.3	+10.9	+11.4	+ .9	+1.2	+8.8	+9.2	−3.3	−3.4
II.	− .7	− .3	−4.0	−4.6	− .9	− .7	−1.6	−1.0	−1.3	−1.2	− .1	− .2
IV.	− 2.9	− 3.3	−6.1	−7.0	+ 3	+ 2.9	+ .2	− .4	+ .8	+1.1	− .3	− .3
V.	+ 3.5	+ 3.9	−3.6	−3.1	− 4.5	− 4.7	−1.0	− .8	− .8	− .6	−1.8	−2.1
VI.	− 4.8	− 4.4	+ .8	− .4	+ 6.4	+ 6.2	+1.6	+1.8	+7.4	+6.8	+1.3	+1.0
VII.	+ .3	− .8	+ .7	− .6	− 1.8	− .4	−1.5	−1.2	− .9	− .3	−1.4	− .8
VIII.	+ 3.7	+ 5.1	+1.7	+1.4	0	− 1.1	+3.8	+4.0	+1.9	+ .1	+2.8	+3.6
IX.	− .4	− 1.8	−4.6	−5.8	− 1.1	− .1	−2.4	+1.9	+1.6	+2.1	−3.3	−2
Average.	− 1.4	− 1.5	−2.2	−3.1	+ 1.5	+ 1.7	0	+ .2	+2.1	+2.2	− .8	− .5
Median.	− 3.5	− 1.3	−2.6	−2.2	− .5	− .3	− .4	− .6	+1.2	+ .6	− .9	− .8

To supplement the graphic records in Pl. I., the significant features of the results are exhibited in Table IV. Here a minus sign indicates 'keener sensibility' and a plus sign the opposite.

The after-test as compared with the before-test shows a gain in sensibility, if we consider the average or the median for

the eight records, and the gain is practically equal for the two ears. But, in view of the radical divergences in the records, very little significance can be attached to the average or median.

The average and median for the ear used as compared with the average of the long test show an approximately equal distribution above and below that average, both in the before- and the after-tests, although the deviations on both sides are large.

There is a closer agreement between the end-tests and the respective adjacent ends of the long record; there is a slight tendency for the before-tests to be inferior to the first hundred acts of the long record, and for the after-test to be slightly superior to the last one hundred acts in the long record. This shows how the sensibility in the end-tests depends upon what portion of the hour-wave such a test is taken in.

There are special explanations for some of these divergencies. The receiver was not tied on, but was held to the ear by the hand, and slight changes in the adjustment would cause differences in the intensity of the sound. The pain from continued pressure may have influenced some observers in the adjustment of the receiver for the after-test. The subjective conditions of the end-tests as compared with the main experiment, and of the end-tests as compared with each other, seemed to influence different individuals in different ways. Thus, in the before-tests, the initial impetus of volition came in to the greatest advantage; in the main experiment, the calm adaptation to a uniform act was effective; and, in the after-test, the heightened irritability and the sense of opportunity for a final spurt played significant rôles. We had hoped to eliminate these and many similar sources of error by taking the test on both ears, both at the beginning and the end, and by making the end-tests of the same nature as the main experiment. But the data obtained are significant chiefly in pointing to individual differences and complexities of conditions. Three[1] of the records (I., VI., VIII.) show a decidedly greater gain in the ear used, one (VII.) shows neither gain nor loss in either ear, and four

[1] To these may be added a fourth, taken on Observer III., but not included in the table because it was taken under somewhat different conditions.

(II., IV., V., IX.) show a decidedly greater gain in the ear not used.

Introspective Accounts.

A general view of the experiences in a period, especially the difficulties and sources of error, may be obtained in part from the introspective accounts. In the following extracts from the accounts which were written by the observer immediately after the experiment, the language of the observer is used, but irrelevant material is cut out and much is abridged.

I. (D. S.) 10:25 a. m., April 16, '04.

The only disturbances that were noticed in this experiment were due to my changing position on the chair. * * * This occurred three or four times. It is my impression that the threshold was about the same at the end of the record as at the beginning, for the reason that I felt scarcely any fatigue from the work. There were places about the middle of the record where there was a tendency to become inattentive and sleepy. There was also a strong tendency throughout the entire period to react rhythmically.

II. (G. H. K.) 9:54 a. m., April 21, '04.

The observing-room was cold, owing to a mistake in the ventilating. A subjective sound was heard all the time, especially at first; this was very confusing. I expect to find great irregularities in the record. The duration of the sound varied greatly. There were several drowsy periods during which there was a tendency to fall into rhythmic action. The time seemed long. During the last half hour I felt much discouraged. I had visual imagery of what was going on in the recording-room. My imagination was very active the whole time.

III. (C. E. S.) 9:54 a. m., April 12, '04.

Only light work before the experiment. Air good, and a good day in general. The only discomfort I suffered was in holding the receiver. It should be tied on both to avoid fatigue and to secure constant adjustment. Slight movements of the receiver cause both qualitative and intensive changes in the sound.

I suffered no serious mental strain, still I found that I held my mouth open all the time so that my throat felt parched at the end of the experiment. I did not have any sleepy spell. There was nothing particularly wearying in the process. The quiet and darkness of the room are so soothing, the stimuli are so delicate and graceful, and the feelings of expectancy are so generally satisfied that I experienced an agreeable complaceny and comfortable adaptation as the experiment progressed. I did not get tired and felt no relief from the change at the end.

The duration of the sound seems to fit my attention-wave nicely. The gradual rise and fall of intensity led me to image a combined auditory, visual, and motor-wave which was decidedly pleasing and had great carrying power. Any interruption in this wave was disturbing, but such disturbances sometimes served to make me more alert. There was a tendency for me to shorten the period in the rhythm and 'rush' the experimenter, and I had to break away from that periodically.

The experiment is conducive to mind-wandering. The noticing of the *To* takes but a small fraction of the time and then one soon learns to estimate the time for the *Tu* from the strength of the sound immediately after the response to the *To* so that there is a freedom from suspense which really should be present.

IV. (C. P. S.) 1:32 p. m., April 26, '04.

(The account of this observer gives a vivid description of the characteristic experience during a period, and is, therefore, inserted in full.)

My physical condition was not of the best, for a severe cold made it impossible for me to breathe through my nose, consequently the whole of the mucous membrane of my mouth and throat became exceedingly dry and parched, necessitating a considerable degree of effort and swallowing to moisten it. Invariably these muscular efforts of my throat and tongue made my sense of hearing seem very much less keen, and on nearly all occasions I was compelled to give the 'objective' signal. This condition was to be noticed more during what might be judged to be the first half of the period than during the latter half; but was nevertheless a frequent factor to be dealt with.

The first portion of the period seemed on account of its novelty and my comfortable position to pass rapidly, and to be full of interest. My attention turned naturally to the experiment in hand, and I felt that I was making a splendid record, for the intervals between my responses were very short. However, as the comfort of my position decreased, and the necessity for changing the position of my limbs and body grew, my attention waned also, until I was suddenly called back to the matter in hand by what seemed an unusually loud and prolonged sound in the receiver. I felt such a time to be proper for a change in position, which I made, at the same time giving the signal. Immediately thereafter I again became conscious of a greater degree of attention.

During about the middle portion of the period, and again later, an element of disturbance arose; namely, the penetration of sound caused by someone walking in the nearby corridor. This distracted me considerably and I gave the objective signal, after which my degree of attention again increased.

A desire to leave my position and stretch body and limbs became almost irresistable during the latter portion of the period; but the belief that the period might be nearly over kept me to my task. A further desire to know how much time had passed returned repeatedly; but this was thrust away by the argument that if I turned on the light and consulted my watch, my attention would be completely distracted, if for only a moment, and the validity of the experiment impaired. This train of thought and the first desire mentioned both contributed to my lack of success in quickly discriminating between silence and sound.

A frequent desire for deep inhalations of breadth, something like yawning came over me, and my yielding to the desire was the cause for several of my signals.

One thing I noticed at intervals throughout the experiment was the loud and violent beating of my heart. This usually followed some change of position and was quite a disturbance. I was most conscious of it when giving almost breathless attention to the receiver. Pulsation of the blood in my temples was also almost sufficient to drown the fainter sounds in the receiver.

Toward the end of the experiment I became conscious of a considerable pressure, almost equal to pain, in the pinna of my ear, caused by the receiver.

At one time a train of thought about my foot-racing started in my mind and I experienced the same violent throbbing of the heart and tingling of the nerves which I experienced just before every athletic contest. This was another source of disturbance, but concentration of attention was sufficient to cause it to disappear as quickly as it came.

The long sound in the receiver which indicated the end of the experiment proper caught me in a perfectly passive condition, responding automatically to the stimuli. I received it, however, with considerable relief, and yet with a certain reluctance for which I cannot account.

So far as I can tell, there was no difference in the preliminary test in the hearing ability of either ear. In the final test I noticed no difference in the relative hearing ability of the left ear as compared with the preliminary test or as compared with the experiment proper. When testing the right ear, however, the first few tests were very poor on account of an improper adjustment of the receiver. With the assistance of the left hand I then held this in a better position, responding with the right hand. The strain of the awkward position of the left arm made me very attentive to it as well as to the receiver which it supported; and I found my hearing ability in this ear so far as I could tell, to be better than that of the left.

When the experiment was over I felt as though I had just finished a period of severe study. No great degree of physical fatigue was noticeable. At no period during the experiment was I able to judge of the amount of time which had passed.

During the first part of the period I sat with my eyes wide open staring into the dark. Many flashes of colored light were visible. Later I sat with my eyes shut because of fatigue in my eye-lids and the distraction caused by winking. With my eyes closed I also observed the many colored lights.

V. (M. B. C.) 9:35 a. m., April 15, '04.

I was in good physical condition. The period was quite free from disturbances, except such as came from slight changes in position. During the first third, I was conscious of my breathing and of both mental and physical strain. During the second third I was conscious of fatigue of both mind and body, and of mind-wandering. Expected the experiment to end. During the last third there was a sudden sense of relaxation and ease, mentally and physically. With the exception of pain from the pressing receiver, this period was the most comfortable and I felt a keener interest in the test than before; but I was aware of making many mistakes. During the whole experiment I had about five or six distinct cases of mind-wandering.

VI. (M. C.) 8:42 a. m., April 19, '04.

For the first fifteen minutes or half hour, the test seemed entirely pleasant and I seemed to be in a sort of a dream. This part of the record is probably best. After that my head began to ache on account of the bandage, aud that distracted my attention somewhat. During the entire test I could notice that my attention would be exerted in waves and it seemed that after a slight movement of the head the record would improve for a time. The headache made the test seem extremely long and tiresome. I began to anticipate the end of the test at what I should judge was about the middle of it. Early in the test, before it became unpleasant, I caught myself falling asleep although I did not

seem to be drowsy. The quality of the sound seemed to change from time to time. There also seemed to be a difference in pitch and the higher sounds were much easier to hear.

VII. (R. E. K.) 1:33 p. m., April 25, '04.

During the first half hour it was easy to keep the attention on the work and I think my keenness of perception was gradually increasing without any marked rise or fall. The next half hour was made up of irregular rises and falls, and it was harder to focus attention, due in part to the discomfort caused by the receiver and by the limitation of movements. It was easier to give attention to the work, after varying the position, *e. g.*, from the erect position to leaning on the table. Gradually I became drowsy and 'came to' with a start thinking that I had neglected to respond; this tended to focus my attention upon the sound for a while. These periods were quite short and were followed by drowsiness. At about the beginning of the last half hour, or twenty minutes, I succeeded in rousing myself. I think the record was gradually growing better at the end of the experiment. I am sure that my threshold was lower at the end than at the beginning of the experiment. During the last half hour it was not difficult to give all my attention to the work; no thought was given to time as was the case in the middle of the experiment.

VIII. (O. H.) 9:35 a. m., April 18, '04.

During the first ten or fifteen minutes of the experiment, the pulse beat was perceptible in the head. Perhaps this was due to the band which held the receiver against the ear. About the end of the first twenty minutes I experienced, but only for a moment, a peculiar lack of sensibility or a numbness all over the body. The experiment seemed long. For a few minutes near the end of the experiment I was disturbed by continual swallowing of saliva. Part of the time the experiment seemed rhythmical. I felt weary from continuing in the same position.

IX. (C. G.) 1:31 p. m., April 20, '04.

I was in good physical and mental condition. Felt sleepy about three times. Shifted the receiver twice because it hurt the ear, but do not think that that caused much disturbance. The time seemed long.

X. (A. W.) 10:17 a. m., April 9, '04.

I found the sounds of my own body, breathing, etc., somewhat of a disturbance at first. It was often necessary to take a long breath to catch up. My arm and hand holding the receiver went to sleep. A queer feeling was also felt in the other hand. At first I think I gave the signal for the disappearance of the sound before such was really the case, because I was listening for a certain quality of sound. About twenty or twenty-five minutes before the close of the experiment I got very drowsy and was conscious of responding almost automatically, and here I am sure that I listened for a certain sound — not merely sound — and signalled when this particular sound appeared and disappeared. After this I aroused myself and found that I could distinguish the beginning of sound which was much fainter than the 'certain' sound I had heard before.

The time seemed short, perhaps two-thirds as long as it actually was. I had a distinct feeling of aloneness when the sound ceased and a mental image

of the sound was present all the time. Sometimes I pressed the key to keep out the sound, which was then more like a presence than a mere sound.

Series II. Discrimination.

Problem, Apparatus, Method, and Observers.

The same plan as was pursued in the study of sensibility in Series I. was here pursued in the study of discrimination. Experiments consisting of an uninterrupted series of determinations of the sensible discrimination were carried on for two-hour periods. The act remained uniform throughout, accessory conditions were kept as constant as possible, and the observer was expected to exert the maximum effort in attention to the act.

The act studied consisted in *determining whether the second of two consecutive sounds, which differed in intensity only, was stronger or weaker than the first.* The same apparatus was used as in Series I. and the conditions of the observer were also similar. The threshold of hearing was first determined and then a point about ten units above that was made the standard. In minor details three different methods were used.

In the first two experiments, Records I. and II., the sound was started at the standard and sounded two seconds at this and at each successive point, the movement being either up or down, and the observer gave a signal as soon as he knew whether it was weaker or stronger than at the beginning. Two signal keys were used: pressing the right hand key indicated a stronger and, the left hand, a weaker sound. Immediately after the response the experimenter cut off the sound for an instant while sliding the carrier back to the standard. This interruption served as a signal for the beginning of the next act. An assistant recorded the responses and the amount of change required for each successive act of discrimination, as indicated by the audiometer.

The next three experiments, Records III., IV., V., differed from the first in the following respects. The sound was held at the standard approximately five seconds, instead of two as before, and the rate of change was not perfectly uniform because the experimenter did not use the metronome. The response was made by one key, one tap denoting stronger and two

taps weaker. In experiments III. and V. a time signal was given to the observer every fifteen minutes.

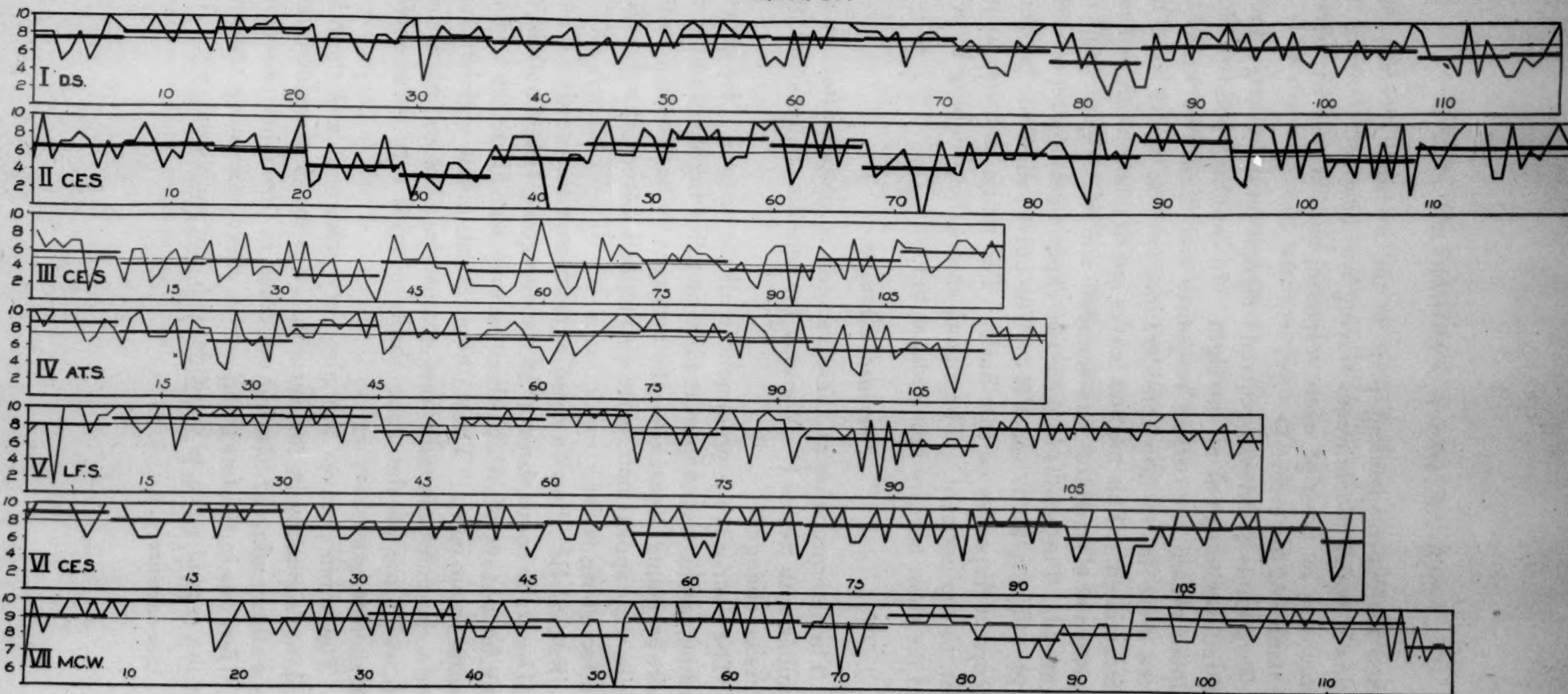
The results of these five experiments are represented graphically in Plate IV., Fig's I. to V. As it turned out that more than half of the responses were made for a single step of change, it was found practicable to use the number of correct responses in a single step of change as a measure of the efficiency. Since nearly all the responses which were not made for one-step changes were made for two-step changes, the method reduces itself to the tabulation of the number of correct responses on the smaller step. But this makes it necessary to deal somewhat arbitrarily with the incorrect responses on that step. Since the chances were equal that a response would be right or wrong, one correct response was deducted from the total with every error; thus, if there were eight correct responses and one wrong, the final record would read, 70 per cent. right. The zigzag line shows the average number of correct responses, on this basis, for each successive ten acts. The short horizontal lines denote averages for a hundred acts each. The long horizontal line shows the average for the whole record. The time is marked in minutes on the base-line.

Experiments VI. and VII. were made by the method of right and wrong cases. A metronome with relay was introduced into the circuit in such a way that the sound was cut out for a second every alternate second. Either the standard or a compared tone, perceptibly different in strength, could be sounded at the will of the experimenter; but it was agreed that the standard should never be sounded more than twice in succession and the compared sound not more than once at a time. The experimenter made the change by sliding the carrier while the sound was interrupted.[1] The observer was required to signal every time the compared sound was heard.

The carrier on the audiometer (to show whether the standard or the compared sound was given), the metronome (to furnish a time-line and to indicate the duration of each sound) and the observer's signal key (to register the signal) were con-

[1] The difference was three steps on the audiometer in experiment VI., and two steps in experiment VII.; and the compared sound was weaker than the standard in the former and stronger in the latter.

PLATE IV.



nected with corresponding pens in the multiple recorder[1] by means of which a continuous tracing was obtained showing the correctness or error of each response, and, in case of errors, the nature of the error.

Two kinds of errors occurred: signals on the wrong sound, and failures to signal on the right. In counting points for the graphic record, the correct responses and these two kinds of errors were taken into consideration, but the errors were not differentiated. This method leaves out of count all those cases in which the standard was sounded and the signal properly withheld. The results of these two experiments are represented in Pl. IV., Fig's VI. and VII. The curves show the per cent. of correct responses on this basis. The range is from 50 per cent. to 100 per cent. The zigzag shows the grouping by tens and the short bars by hundreds, as before.

Periodic Changes.

The interpretation of these records is simple, after we are familiar with Series I. We look for periodic changes and progressive changes.

The hour-wave is prominent in all the records. Its general outline can be traced most readily by following the trend of the short horizontal lines, *i. e.*, the averages by hundreds. In this series they appear both more distinct and more uniform than in the foregoing series.

Record III. shows a close agreement with records III. and XIII. on the same observer in the foregoing series, both in the long hour-wave of which there is only one phase, and in the shorter hour wave. These three records taken together indicate a characteristic individual wave series; but records II. and VI. which are on the same observer agree with these only in the shorter hour-wave.

The minute-waves are also very prominent and there is a striking similarity in the records. But the present method is not entirely adapted to bring out detail in these short waves.

Here, as in the foregoing series, there is a strong tendency for the second-wave to coincide with the individual act. The

[1] See reference, p. 60.

time was suitable, and the new effort made at each beginning on the standard was conducive to the adjustment of the attention-wave to the duration of the act.

The distraction of introspection was avoided, as far as possible, in the regular experiment. But afterward, some experiments were repeated for the purpose of determining by introspection whether the combination of active and passive attention follows the same principle in the act of discrimination as in the act of simple perception.

We may illustrate the conclusion by reference to the simplest form of comparison in discrimination. In Fig. 14, let the dotted figures *AB* and *CD* represent two successive tones. The duration of each tone is one second and the interval between them is one second. The act consists in determining whether the two tones are equal or different in intensity.

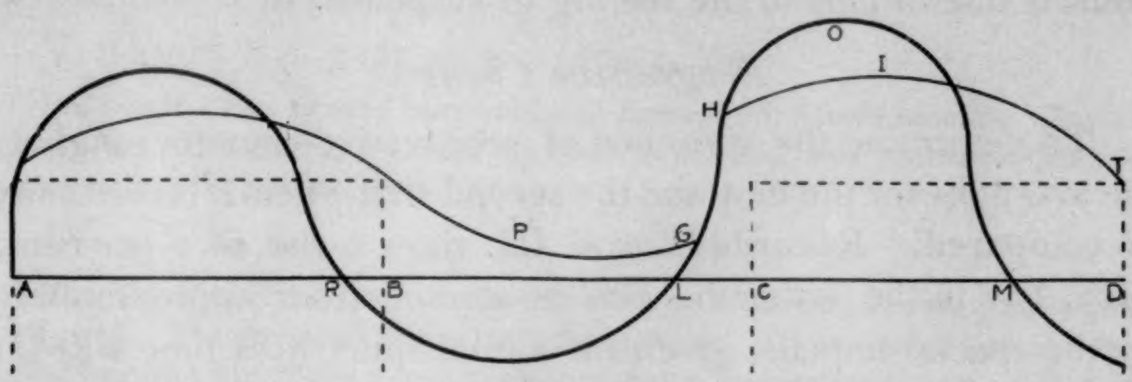


FIG. 14.

The general form of the attention-wave in which the whole act is comprehended may be outlined by the composite curve *ANPOJ*.[1] But this may be reduced to its component elements; namely, the secondary passive wave *APGHIJ*, and the two active attention-waves *ANR* and *LOM*. That is, the combination follows the same principle as was illustrated for sensibility in Fig. 12, p. 63: the act is performed largely by secondary passive attention, but at the critical points, short intensive waves of active attention occur.

This illustration presupposes a trained observer performing a familiar act under the conditions named. The proportions of the components would vary with observers and conditions, but

[1] *N* was cut out from the etching inadvertantly; it represents the first active attention-crest and is symmetrical with *O*.

certain relative features are rather fundamental. (1) The two stimuli and the memory image of the former are grasped in a single wave of attention. (2) Active attention comes into prominence only at the critical moments. It does not cover more than the first part of each stimulus and the end of the memory image. (3) Both forms of attention rise higher for the last than for the first stimulus. There is also a wider scope of attention at the beginning of the second stimulus but this cannot be represented in the plane figure. (4) The early rise of the second active attention-wave is due to the effort to grasp the passing memory image and to take advantage of the sharp edge of the appearing stimulus. The rise of the passive wave at the same point is due in part to the feeling of suspense.

Progressive Change.

To determine the presence of progressive change roughly, the averages for the first and the second half of each record may be compared. Records II. and III. show a rise of 6 per cent. each, but in the latter the rise is accounted for approximately by the special impetus given for a final spurt by a time signal; and in the former, the absence of the usual high beginning for this observer is conspicuous. Five records show a decline in ability as indicated by the following per cents. respectively: I., 8 per cent.; IV., 3 per cent.; V., 10 per cent.; VI., 1 per cent.; and VII., 2 per cent. On the whole, therefore, there is a tendency toward decline in ability in this period of work.

Notes from the Introspective Accounts.[1]

I. (D. S.) 9:30 a. m., June 8, '04.

I was in good condition for the test. Felt drowsy for three-fourths of an hour about the middle of the experiment. I also felt drowsy for a quarter of an hour after the experiment. The duration of the sound at the standard seemed to vary; this was disturbing.

III. (C. E. S.) 3:10 p. m., June 4, '03.

Good physical and mental condition. In the fourth quarter I had difficulty in keeping awake. Each quarter-hour signal aroused me to a keener discrimination. The signal gave a feeling of relief. I often moved slightly and the change of position broke the monotony. The absence of light was exceedingly soothing.

[1] Abridged as in Series I.

There was no sense of increased fatigue during the second hour. In fact I felt brighter in the second hour than in the first, especially in the approach to the end.

The errors are due to various reasons. Among the objective, the following may figure: the uncertainty of the tap on the key, movements of the receiver, and irregularities in the time of the stimulus. Among the subjective factors, are, mind-wandering, failure to remember the standard, and hesitation in reaction.

The observer felt no after-effect of the experiment until 9 p. m. Then he felt an unusual pain above the eyes and a more decided feeling of general exhaustion than usual. There are no means of knowing whether these effects were or were not due to the experiment.

IV. (A. T. S.), 2:45 p. m., June 3, '03.

The period seemed short. I felt sleepy once and caught myself distinctly mind-wandering twice. I enjoyed the experiment and took special pleasure in the opportunity to do my best.

V. (L. F. S.), 3:35 p. m., June 3, '03.

I felt as if I had swayed backward and forward for fifteen seconds. In the last quarter, or half hour, I gritted my teeth as if I had been running an engine down grade. Do not feel tired.

VI. (C. E. S.), 2:33 p. m., April 7, '04.

The experiment began immediately after an afternoon lecture from which I felt tired. The step seemed too large throughout. There was no considerable period during which I felt any distinct incapacity for discriminating. The mistakes seemed to come singly, and most of them could be traced to some temporary inattention, movement, distraction, or lapse into rhythm. I was quite comfortable all the time. The darkness and silence of the room were distinctly restful and quieting. I felt a distinct relief from the strain of the lecture room and from stimulation of the eyes, and thought that this room would be an ideal resting place.

The work was not exhausting. There was a distinct tendency to automatism. It was possible to carry on a process of reasoning without making any mistakes in the discrimination. (?) It may be that the tendency to perceive rhythmic accentuation (intensification) led me to think that I was right when I was not.

The time seemed to drag, *i. e.*, I kept accelerating and had to realize from time to time that my subjective standard of time had changed. I was sleepy once, at the end of the first fifteen minutes.

I had a distinct and helpful pitch association. The strong tone seemed to be the fundamental (do) and the faint seemed to be the fifth of the octave below it (sol). I frequently judged entirely by this pitch difference, which was probably due to the prominence of the first overtone in the stronger sound.

VII. (M. C. W.), 3:40 p. m., June 11, '03.

The quality of the tone varied. The time passed quickly, and I did not feel tired at the end. I had short lapses of attention which seemed to serve as periods of rest, but I exerted a strong effort all the time. During the first fifteen

minutes I felt dizzy. There was a strong space association, the weaker sound being localized further away.

SERIES III. MEMORY.

Problem, Apparatus, and Method.

The following requirements were kept in mind in the planning of this test: (1) The work shall consist of a difficult act of memory which shall be repeatable under uniform conditions, without interruption, for any desired length of time. (2) There shall be only one variable element in the complex act; all variable associations and disturbing sensory stimuli shall be eliminated as far as possible and the motor process shall be reduced to a minimum and uniform act. (3) All elements in the complete act of memory, namely, impression, retention, reproduction, localization, and expression, shall be involved in the same way at every step. (4) The work shall be the result of continuous maximum effort. (5) A detailed record of efficiency shall be obtainable.

With these ends in view, the following act of memory was chosen: *Given four clearly distinguishable intensities of the same tone in succession, to signal the order of succession in a group after the order in the next following group has been observed.*

The psychological relations of the intensities of the tones may be represented by the relations of these lines:

Number 4 was so faint that it could just be heard distinctly, 1 was as strong as it could be without being disagreeable to the ear, and 2 and 3 were adjusted between these limits empirically in such a ratio that the steps 1–2, 2–3, and 3–4 were equally perceptible.

The procedure may be illustrated from the beginning of an experiment by giving the part of the observer, as follows:

Receives the first group, *e. g.*, 2134.
Receives the second group, *e. g.*, 3214.
Reproduces the first group, 2134.
Receives the third group, *e. g.*, 2413.
Reproduces the second group, 3214.
Receives the fourth group, *e. g.*, 4132.
Reproduces the third group, 2413.
Receives the fifth group, *e. g.*, 1423.
Reproduces the fourth group, 4132. Etc.

Thus the same act, namely, *observing the order of four sounds in a group and reproducing it after another group has been observed*, could be repeated for any length of time without serious change in the setting or relative value of the elements in the group. The selection of this particular act made it possible to comply approximately with all the five requirements enumerated above.

The sounds were produced through a telephone receiver in the secondary circuit of an inductorium, the primary circuit of which was completed as a shunt around a 100 v. d. electric tuning-fork.

A system of four open-circuit keys was inserted in the primary circuit of the inductorium. Each of three of these was in circuit with resistance coils, respectively, as follows: key 2, 35 ohms; key 3, 670 ohms; and key 4, 4,845 ohms. By closing a key, the inductorium circuit was completed through the corresponding resistance and this change in the current produced the desired gradation of the sounds heard in the receiver. This gradation was determined empirically by a sufficient number of trials. The experimenter produced the stimulus sounds by playing upon these keys.

The observer signalled his reply by a similar system of keys, each of which was associated with a given sound. Thus, the sounds were numbered 1, 2, 3, 4, in order of their strength, beginning with the strongest, and the keys were numbered 1, 2, 3, 4, running from left to right. Hence, if the sounds appeared in the order 3, 2, 4, 1, the proper reply would be to press the response keys in that order.

A record of the stimuli and the responses was taken in a

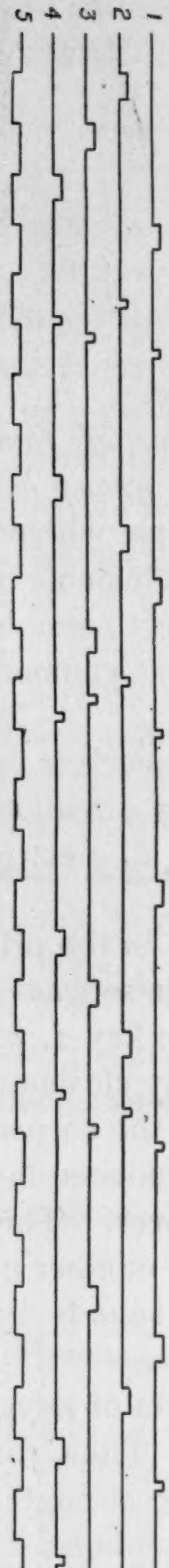


FIG. 15.

continuous tracing by the multiple recorder.[1] Each of the stimulus keys was connected with a pen on the recorder, and each of the response-keys was connected with the same pen as the corresponding stimulus key. The fifth pen in the recorder traced a time-line in seconds. A portion of a record is reproduced in Fig. 15.

Each section contains first the group of four stimuli and then the group of four responses to the group received in the preceding section. Thus, the first response we cannot tell anything about because the stimulus is not on the record, but the second response is correct because it corresponds to the first stimulus group: the third response is wrong in part because it reads 4, 2, 3, 1, instead of 4, 2, 1, 3; and the fourth response, again, is correct. The record also shows the time of each stimulus and each response.

In regulating the time-order, the experimenter was guided by the beat of a metronome. The record shows that the sounds were produced at the rate of one per second, and that each sound lasted one half second. It also shows that an interval of four seconds was allowed for each group response and that the individual responses were given short and in quick succession so that the observer saved some time in which to change from the expressive to the receptive mental attitude.

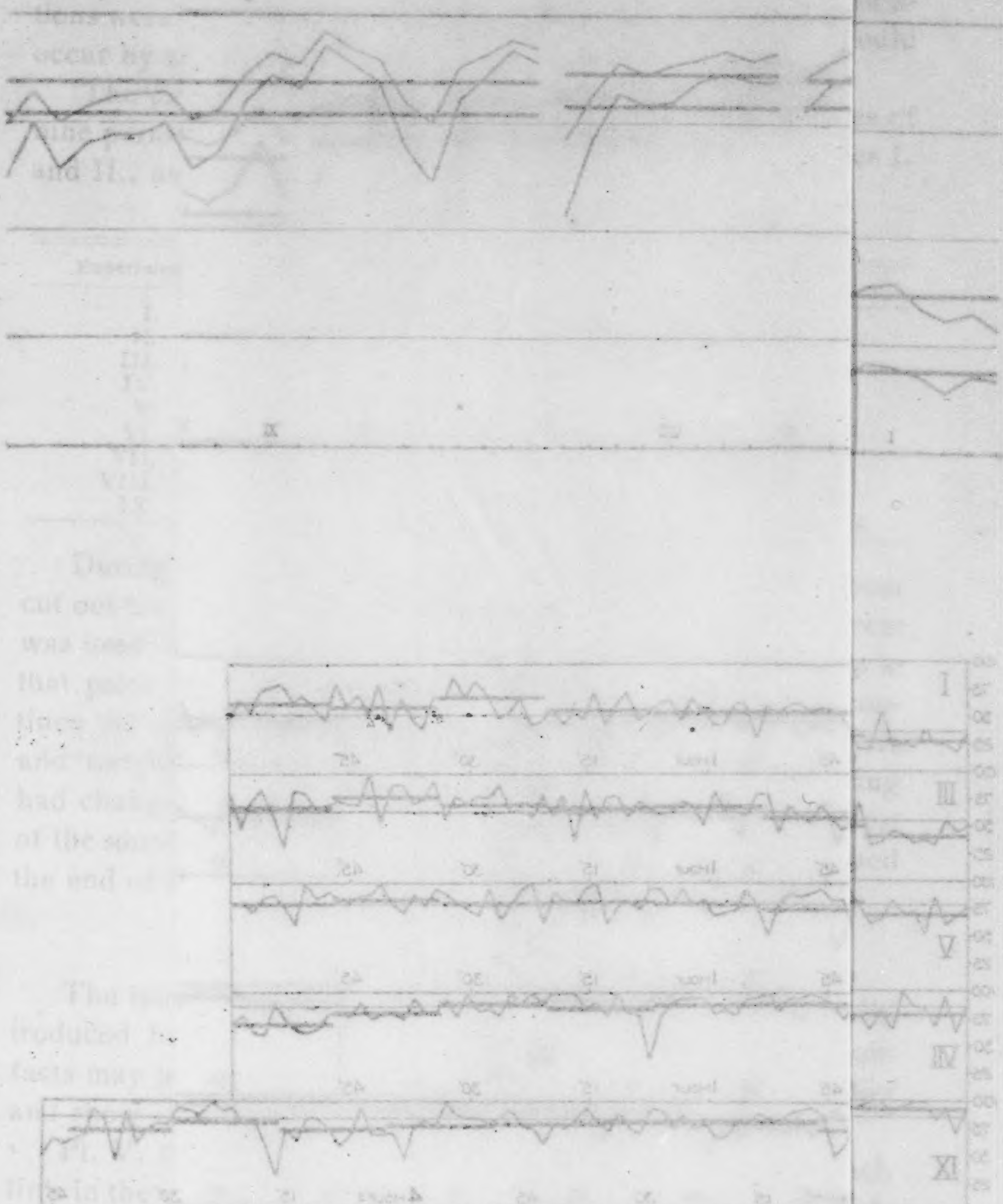
The apparatus was distributed in three rooms: the telephone receiver, the response keys, and the inductorium were kept in the observing room; the fork was kept in the distant battery closet, and the experimenter had the remaining parts in the measuring room. The observing room was moderately lighted with an incandescent light.

There are twenty-four possible mutations of the stimulus group with four sounds, but as two of these (1234 and 4321) are decidedly easier than the

[1] See references.

rest they ...
tions ...
occur by ...

nine ...
and II., ...



Durin...
cut out...
was ...
that ...
...
and ...
had ...
of the ...
the end ...

The ...
(reduced ...
facts may ...
an...

line in the ...
The base ...
each act ...
time units ...
The time ...
the begin...
The per ce...

PLATE V

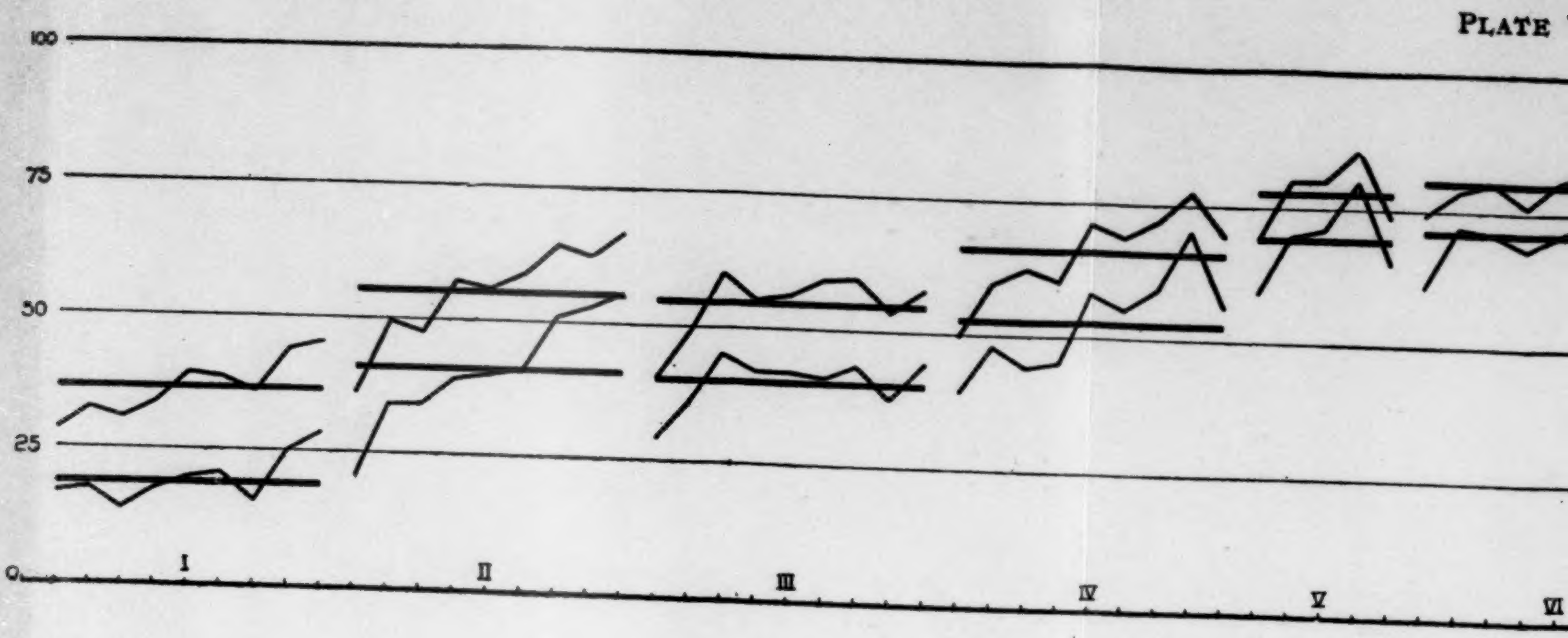


PLATE VI.

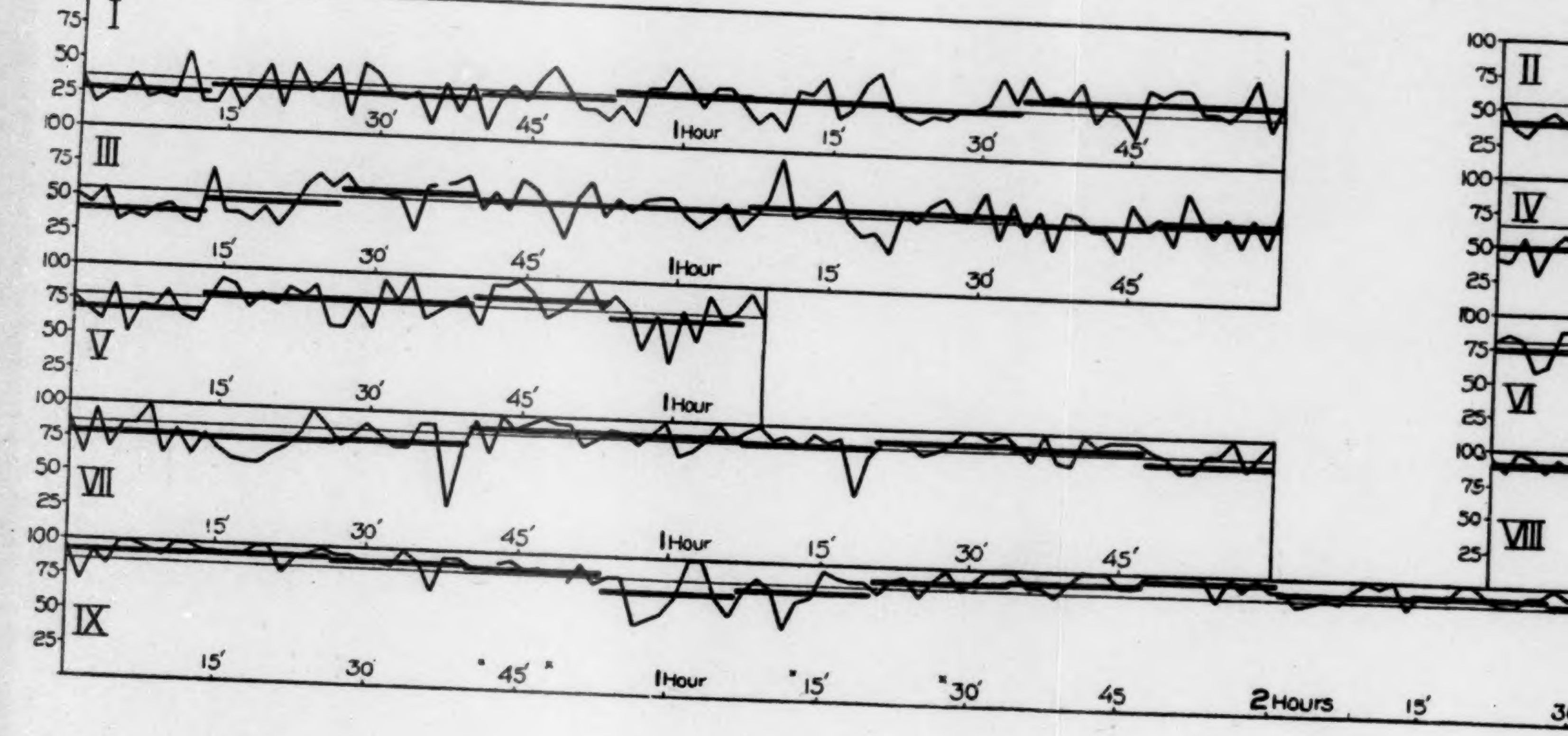


PLATE V.

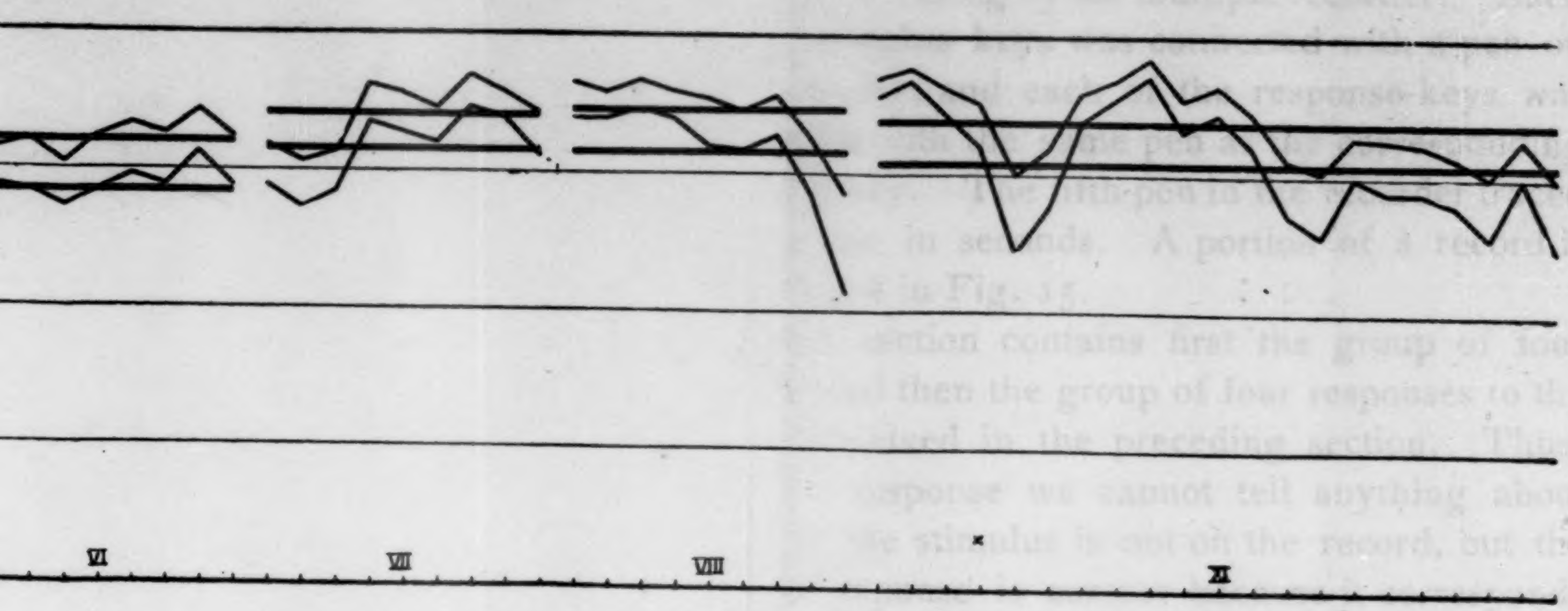
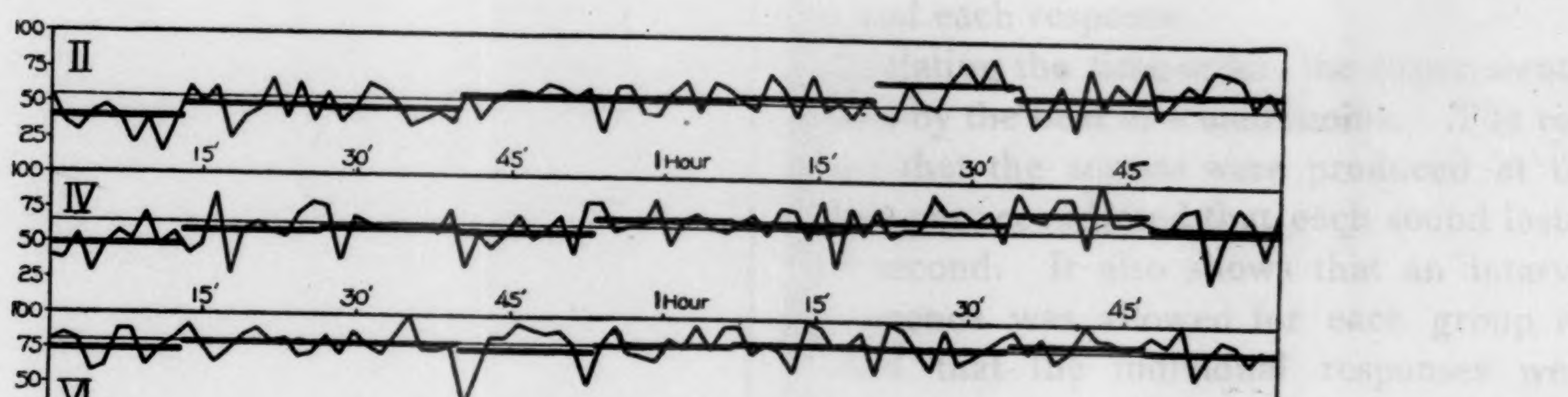


PLATE VI.



rest they were excluded and the remaining twenty-two mutations were used approximately in the order in which they would occur by chance.

The experiments here reported consist of a single series of nine periods taken upon one observer, Observer I., in Series I. and II., as follows:

LIST OF EXPERIMENTS.

Experiment.	Date.	Began.	Continued.
I.	Feb. 9	9:04 a. m.	2 hours.
II.	" 11	9:04 "	" "
III.	" 16	9:15 "	" "
IV.	" 18	9:08 "	" "
V.	" 20	8:37 "	1 hr. 13 min.
VI.	" 23	9:14 "	2 hours.
VII.	" 25	9:13 "	" "
VIII.	Mar. 1	8:57 "	" "
IX.	" 3	7:29 "	4 hrs. 48 min.

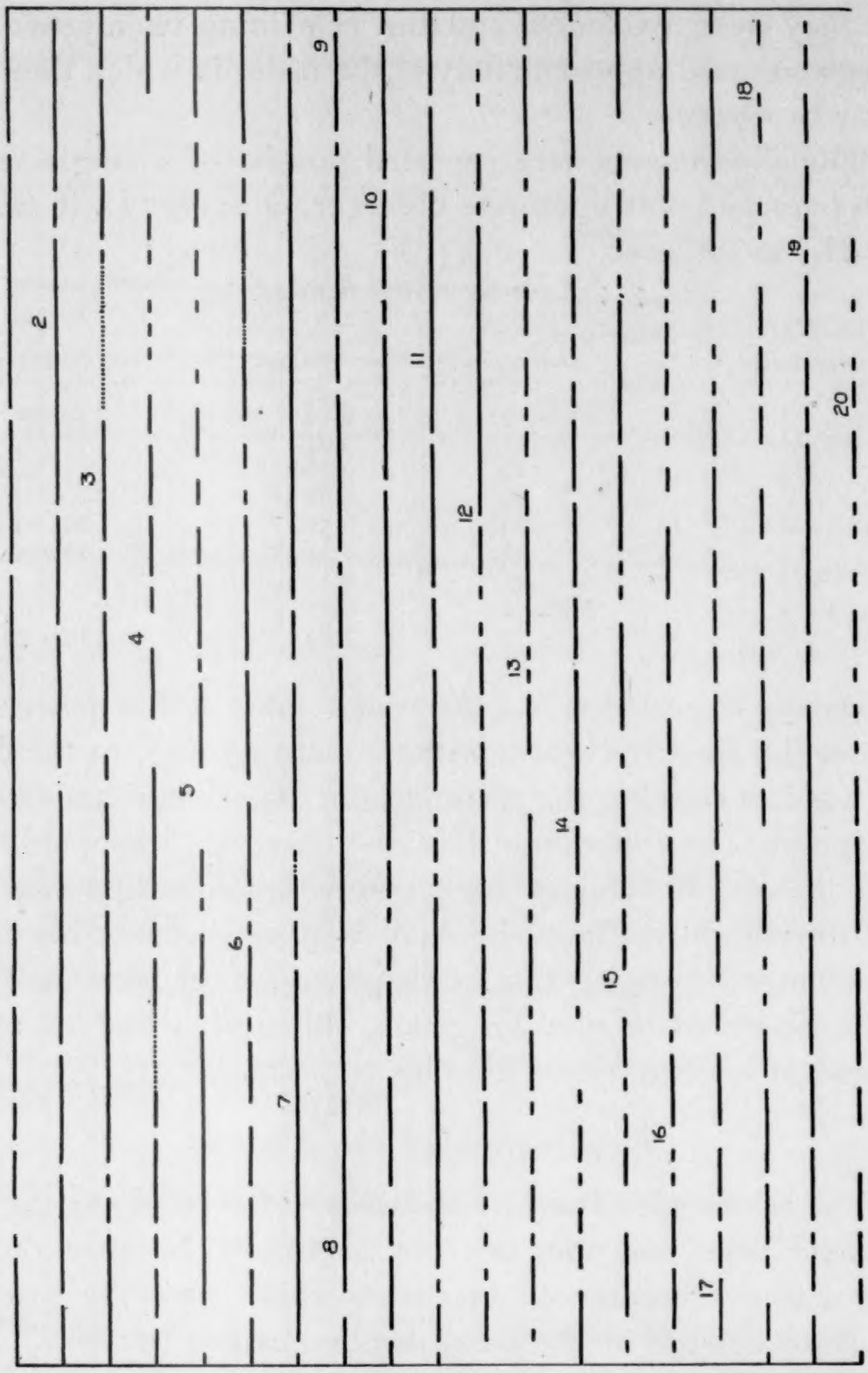
During experiment V., the repair man at the power house cut out the electric current without warning and, as the current was used in running the recorder, the experiment had to stop at that point. In experiment IX., the observer attempted to continue the test as long as he possibly could. After four hours and forty-eight minutes, he had to cease because his hearing had changed so much that he could no longer hear the faintest of the sounds in the stimulus group, although he had not reached the end of his endurance in other respects.

Explanation of the Records.

The tables of numerical results are too extensive to be introduced here, and they are not necessary, because the main facts may be represented in curves which give the true relief and show enough of the detail for the present purpose.

Pl. V. shows the results of the whole series *en gros*. Each link in the curve as a whole represents one experiment period. The base-line is laid off in units of one hundred acts. Since each act takes eight seconds, these units may also be considered time units of eight hundred seconds, or 13.3 minutes each. The time-line extends one unit to the left of each curve because the beginning point in each curve represents a hundred acts. The per cent. of success is indicated by vertical distances.

PLATE VII.



The degree of success is expressed in two curves which run nearly parallel. The upper indicates what per cent. of individual signals — out of a possible four hundred — were correct in each group of one hundred acts. The lower curve shows what per cent. of complete acts were correct in the same periods. The difference between the two curves is that successful parts of acts were counted for the former whereas only successful whole acts were counted for the latter.

For the two-hour periods, there are nine points in each curve. The average for the whole period is expressed by a heavy horizontal bar over each curve. By these means we are enabled to see at a glance the general trend of the progressive change and the existence of the long periodic changes. The figure as a whole is a fatigue-curve, work-curve, memory-curve, curve of 'learning,' etc., according as it is viewed from one point or another.

Pl. VI. shows the same results more in detail. Here the record contained in the upper curve of Pl. V. — the per cent. of success, counting both whole acts and parts of acts which are correct — is represented in units of ten acts for each point. Each point in the zigzag curve denotes the average per cent. of success in ten acts. Averages for a hundred acts each are represented by the heavy horizontal bars, and averages for the whole record of a period by a light horizontal line. The numbers of the sections here, as in Pl. V., correspond to the list of periods, dates and durations in the above table. Pl. VI. shows the hour-waves and the minute-waves quite well.

Finally, to show the 'makes and breaks' in the continuity of power still more expressively, the data contained in the lower curve of period IX. are represented in a special manner in Pl. VII. Success in whole acts is represented by a line, and failures by breaks in the line. It shows the distributions of the ratios of success to failure. Thus, from the beginning, the record reads: Nine successes, one failure, one success, three failures, four successes, one failure, three successes, one failure, seven successes, etc. The three small-dotted parts indicate objective disturbances. The numbers indicate the ends of the successive hundreds of acts.

Extracts From the Introspective Accounts.

February 9. — At the beginning of the experiment, I attempted to find some method to aid in the remembering. I tried to remember the sounds by their numbers, by directing special attention to the first two sounds in a group etc., but abandoned these in favor of the attempt to retain the sensory image of the group as a whole. This change of method produced great irregularities in the first part of the record.

February 11. — To-day the series was not so fatiguing and no change occurred in the way of trying to remember the succession of sounds. Toward

the last it seemed comparatively easy and it seemed that a small number of sound conbinations were used over and over.

February 16. — I do not think that this record is any improvement over the last one. I did not feel so bright as last time — possibly on account of the close air in the room. I could not concentrate attention so well. The period seemed longer than the last one. * * * The strength of the sound series as a whole seemed to vary several times * * * in the latter part the sounds seemed fainter for a short time.

February 18. — To-day's record is better than the last one, and possibly better than any preceding record. There were no special disturbances except twice, probably at the change of classes.

February 20. — To-day's record is, I think, an improvement over the preceding. About 85 per cent. to 90 per cent. of the reactions may be correct. * * * The periods of attention and relaxation [minute-waves] seemed to have changed considerably. In the first and the second records I took, I should estimate that the periods of attention and relaxation are about equal, but in succeeding records the period of attention seems to have increased in length gradually.

February 23 and 25. — The observer wrote no introspective accounts on these days, because he had nothing special to record. He was aware of the continued practice gain and in both cases his estimates of the degree of his success was approximately correct.

March 1. — During the last part of this period the sound series seemed to grow stronger so that it caused confusion of the sounds. There were also some irregularities in the duration of the sound stimuli. The direct effect of these disturbances lasted for a short time only, but the thought of them tended to recur and was especially effective in distracting my attention because this took place in the last part of the record when I was fatigued and more subject to it.

March 7. — During the first few records I memorized the stimuli largely by visualization. I responded according to the impression of the successive louder or fainter sounds, not taking notice of particular ones of a group. Then I associated each stimulus with the key corresponding to it, and whenever a group was given I would glance from one key to the other in the same succession as the given stimuli. At the same time one or two of each group began to become more conspicuous on account of their position or intensity, *e. g.*, the first and last ones of a group or the place of the loudest or faintest ones, but especially the former. If the first one and the last one of a group were together, *i. e.*, if the corresponding keys were together, they would be the more conspicuous ones. So my memorizing depended largely upon the reference to the key board. Some groups were more easily remembered than others. Such are, 1324, 4231, 2134, 1243, 3421, 3412, 2341, 3214. In these the conspicuous features were noticed more easily and much earlier than in the others. But the more difficult ones were also memorized in the same way but more slowly, so that some were not thought of by their peculiar features until the last two or three records. These noticeable features of the various groups afforded a basis for 'names' of the groups so that at last I had a name for each group as follows:

(The keyboard was thought of not as a horizontal plane but as an inclined plane of which the end with the loudest sound was up and the end with the faintest sound was down.)

1324 = Zigzag down.
4231 = Zigzag up.
1342 = Two together, up.
4213 = Two together, down.
1432 = One up, three down.
4123 = One down, three up.
2341 = Three down, one up.
3214 = Three up, one down.
2134 = Both pairs from the center, up.
3421 = Both pairs from the center, down.
2143 = Both pairs up, up.
3412 = Both pairs down, down.
2413 = Parallel down.
3142 = Parallel up,
2314 = Two in the center, down.
3241 = Two in the center, up.
1423 = Up, down.
4132 = Down, up.
1243 = Straight down (except the last two are reversed).
4312 = Straight up (except the last two are reversed).
2431 = Triangle below.
3124 = Triangle above.

It never occurred to me until now that the remembrance of these groups depended so much upon the motor action of my right hand as it really does. As I am writing these groups and their 'names' I cannot give many correctly without actually performing the taps as if on the keyboard. After these names had become quite familiar, I had a feeling of confidence that I could give almost every response correctly unless I had been too inattentive to get the group correctly when it was given. Whenever I had clearly grasped a group I was certain that I could remember it with the aid of its names and give it correctly in the response. But before I had these names for the groups the occurrence of the second group would frequently cause me to forget the first, although I had it clearly in mind just after it had been given.

During the intervals between the stimuli I repeated the name of the group to be given after the next stimulus by actual movement of the mouth. I was unconscious of it and did not know it until I caught myself doing it. The movement of the hand in giving the response was almost entirely automatic so that I needed to attend only to the incoming stimuli. I was also unaware of breathing except when I happened to take a deep breath.

During the last record fatigue did not consciously affect me until about the end of the third hour. I became inattentive on account of a drowsy, sluggish or sleepy feeling. Whenever I would take a different position on the chair it would serve to make me more attentive. About a half hour before the end of this record I occasionally felt a stinging pain in my ear. This became more frequent and intense until the fourth or faintest sound was not perceptible at all, and then I decided to stop.

For nearly an hour after, I felt pain in the ear from time to time. I did not seem to be fatigued very much until two or three hours afterward. I felt as though I had done hard manual labor.

In reply to a request for fuller information in regard to the disposition of the time allowed for an act, the observer wrote, under the date of March 18:

As each sound of a combination was given, I glanced at the corresponding key and as soon as the third sound was heard, I knew the whole combination of four sounds so that, immediately after the last sound, I could turn to the preceding combination and respond at once. The reaction was almost automatic. After the response, I returned to the new combination and repeated its name but discontinued this long enough before the appearance of the next sound to be fully prepared. If I failed to allow time for preparation, I frequently failed to get the new combination.

Periodic Change: A. Hour-waves.

The hour-waves are quite as pronounced and uniform in this series as in Series I. and II. They may be seen both in Pl. V. and Pl. VI. Thus running the eyes along the curves in these plates, we see two and one half sinoid waves in each of Periods I., III., VII., and VIII.; three waves in Periods IV. and VI.; three and one half in Period II.; and one in Period V., which is incomplete. (Cf. the records on the same observer in Series I. and II. — Fig. I., Pl's I., and IV.)

About the same length of waves are found in Period IX., but they are here disturbed by the presence of longer waves which seem to be due to the awareness of the length of the task. The great depression of the long wave, one phase of which occupies two hours, is due in part to a temporary disturbance, the stopping of the fork. The points at which the forks stopped are marked with stars in the figures. These disturbances were only of a few seconds duration each and the loss is eliminated in the averaging for the groups in which it occurred.

Periodic Change: B. Minute-waves.

The same minute-waves which we are familiar with from the other series are here in evidence. They appear conspicuously in Pl. VI. in which their regularity is somewhat exaggerated by the want of detail. To show them with absolute fidelity, the record for Period IX. is represented in detail in Pl. VII. but here it is difficult to trace them on account of the confusion of these with the longer waves.

Periodic Change: C. Second-waves.

Here as in the preceding series the second-waves are present and can be obtained by analysis of the act and introspection. The form and combination of the attention-waves go through progressive changes throughout the series. For the purpose of simplifying the presentation, we may examine the distribution at a given stage, *e. g.*, the last record.

Fig. 16 shows in a schematic way the form and composition of the wave in a typical act at this stage, the stage of the highest mastery of method. The long bars 1, 2, 3, 4, represent the time of the four stimuli in the group which is to be impressed. The short bars 4, 3, 2, 1, show the time of the responses to the impression received in the preceding act.[1] There

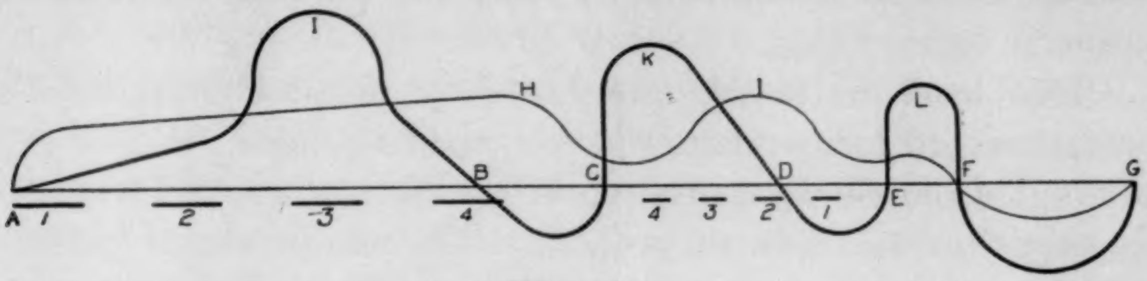


FIG. 16.

are three waves of active attention: *A–B*, to the act of receiving; *C–D*, to the act of responding; and *E–F*, to the repetition of the group which is to be retained. After each of these, there is a depression denoting the absence of this form of attention. The wave of passive attention is continuous for this act, although it shows certain characteristic fluctuations. A glance at the curve reveals these fluctuations better than a verbal statement.

The distribution complies with the general requirement, that the active attention shall be more impulsive and take more rest than the passive. Both forms have negative phases from *F* to *G*, but the active attention has two other pronounced negative phases, namely, *B–C* and *D–E*.

The receiving process clearly divides itself into active and passive stages. The crest, *I*, denotes the fact that, at the beginning of the third stimulus in the group, the fourth was pre-

[1] By mistake in lettering, the two orders, 1 2 3 4 and 4 3 2 1, which were not used, appear in the figure.

dicted and the order of the group was analyzed and impressed, by a well concentrated effort. After a moment's relaxation, there was another decisive mustering of forces in the act of recalling the order which was to be reproduced; the motor process of the response was semi-automatic. Following another moment of relaxation, there was a short but well regulated effort, *L*, in the reviewing of the image which was being retained. Then both forms of attention drop in preparation for renewed efforts.

The actual distribution varies from the type described, not only in the series as a whole, but in successive acts at this particular stage of practice. In fact, the progress of learning might be illustrated in terms of the progressive change in the composition of the attention-wave. So also every temporary fluctuation in efficiency may be described partially in the same terms.

This leads us to the question, Is it possible to maintain a perfect record for two hours in this particular act? All we can say is that the elimination of occasional errors would be an extremely slow and difficult process. The attainment of perfection depends upon the power to adhere to a most economic composition of the attention-wave. The distribution of failures, as shown in Pl. VII., indicates that it is possible to be systematic and successful for a considerable period at a time, but the hour and the minute-periodicities break in and the result is disturbance in the second-wave.

Progressive Change.

Examination of the curves in Pl. V., with reference to progressive change, reveals especially the following features: (1) There is a gradual increase in efficiency from the beginning to the end of each of the first seven periods, provided one neglects the periodic fluctuation and regards only the general tendency. The second and fourth periods show the greatest rise, and the third and sixth the least. (2) Periods VIII. and IX. both show progressive decline in efficiency. (3) There is a tendency for each successive period to start from the vantage-ground gained in the just preceding period. The rise of the series, however, shows three plateaus; the third day is on the same level as

the second; the sixth is on nearly the same level as the fifth; and the eighth and ninth are on about the same level as the seventh. (4) With increasing efficiency, the two curves tend to run closer together.

The curve as a whole is a practice-curve, but not pure and simple, for various other elements are involved in it. The act was appallingly difficult to the beginner. It was so much more than he could do that it required the greatest determination and perseverance in pursuit of the goal — mastery by practice. This goal he never quite reached, yet he came near it, and made a remarkable progress with practice. What was the nature of the improvement? The discussion of that might be considered the principal topic of this report, but we must content ourselves with merely a brief reference to it.

According to the observer's account, supplementing his written introspection, the following were important factors in the learning, or acquisition of power by practice: (1) Distributing energies, (2) finding method of receiving, (3) development of a visual scheme of associations, (4) automatism of the response, (5) naming, (6) repetition, and (7) rest.

Before the recording began, the observer had had no more practice with this act than was necessary to enable him to understand the requirements. At the first attack there was naturally a good deal of hesitation as to what part of the act he should concentrate his energies upon first. It was impossible to give uniform attention to the whole array of parts in the act.

This led to a skirmishing for methods — methods of receiving, methods of retaining, methods of reproducing. This skirmish was most noticeable during the first third of the first period. As a rule he was not aware of deliberately trying this or that method; there was a sort of desperate effort to get something in any way possible, and reflection shows that this resulted in the bobbing up of different methods which may be differentiated.

The general method soon found and afterward followed consisted in falling back upon a very concrete visual scheme of associations which grew gradually toward perfection and real-

ism. The scheme was not merely visual; the motor element was prominent and contributed much to the realism. Consciousness was distinctly visual-motor. The situation was alive! The observer became oblivious to all else and threw himself entirely into this melee. It was not abstract memory; it was a play. Each sound was merely the signal of a combatant who had to be located and his lunge parried.

The development of power in this act of parrying consisted in the formation of automatisms, just as the acquisition of skill does in the fencer. From this point of view, this act of memory resolved itself into a hierarchy of acts in which one grade after another was mastered in succession.

Still improvement consisted largely in progressive unification. Groups were gradually identified as wholes having striking peculiarities which gave rise to names. The names were descriptive and served as motor cues. The identification and naming led to the perception of the limitation of the number of variations, and this resulted in the development of a feeling of familiarity and ease which was decidedly conducive to endurance.

All these shortenings increased the spare time and it soon became possible to take advantage of that by recalling the impression which was to be retained while waiting. This repetition strengthened the retention as soon as it could be done without too much sacrifice of rest.

But the acquisition of time for rest and the habit of the most economical use of this rest constitute the most potent factors in the development of power of endurance.

Features like those here enumerated account for the profit by practice up to the highest point reached. That point seems to be approximately a physiological limit.

The observer accounts for part of the decline in Period VIII. on the ground of objective disturbance. That disturbance seems to have been overestimated and was probably chiefly subjective, but it brought on a mood or attitude which is the chief cause of the depression. For this reason, it is not safe to draw any conclusion in regard to progressive change in this period, except to state that a decline occurred.

The decline in the long final period is pronounced and decisive.

Part IV. General Conclusions.

The conclusions upon individual points are so tersely stated in the text that there is no need of repeating them here; but it may be profitable to restate some of the broader generalizations from the investigation as a whole, stripped of their technical garb.

Our primary aim was to develop methods of controlling and recording definite forms of continuous mental work in the hope (1) that we might pave the way to the experimental study of such facts as fatigue, adaptation, learning, and the effect of various conditions and stimuli upon the efficiency of continuous work, and (2) that certain general characteristics of mental work might be demonstrated in such faithful records. The results may, therefore, be summed up with reference to (1) method, and (2) certain characteristics of the efficiency of continuous mental work: (*a*) periodic change and (*b*) progressive change.

I. *Method.*

The methods here introduced for the measuring of prolonged mental work differ essentially in type from the methods in vogue, such as the adding method, the nonsense syllable method, routine work methods, the ergograph method, etc. Our methods seem to have advantage over every other method heretofore used in one or more of the following respects:

The work is mental.

The work is relatively homogeneous.

The work is reduced to fundamental types and relatively controllable conditions.

The measurements are continuous and in sufficient detail.

The measurements are on the work itself and not on injected tests.

The general principle is adaptable to different types of mental work.[1]

[1] It takes but little ingenuity to adapt the general principle of measurement here employed to the different senses, and to fundamental types of cognition and action. But this is only the first step; the methods must be used under specific conditions for specific purposes, *e. g.*, by Kraepelin's pause-method in the study of fatigue.

II. *Periodicity*.

1. *Periodicity a General Characteristic of Mental Work.*[1] — The three fundamental and representative types of mental activity studied, sensation, discrimination, and memory, exhibit alike a thoroughgoing periodicity. There is a continuous gradation from the period of the momentary active impulse up to the hour-long waves of mental efficiency. The efficiency in a given period, say two hours, may be represented by an irregular wave, the resultant of a series of partials.

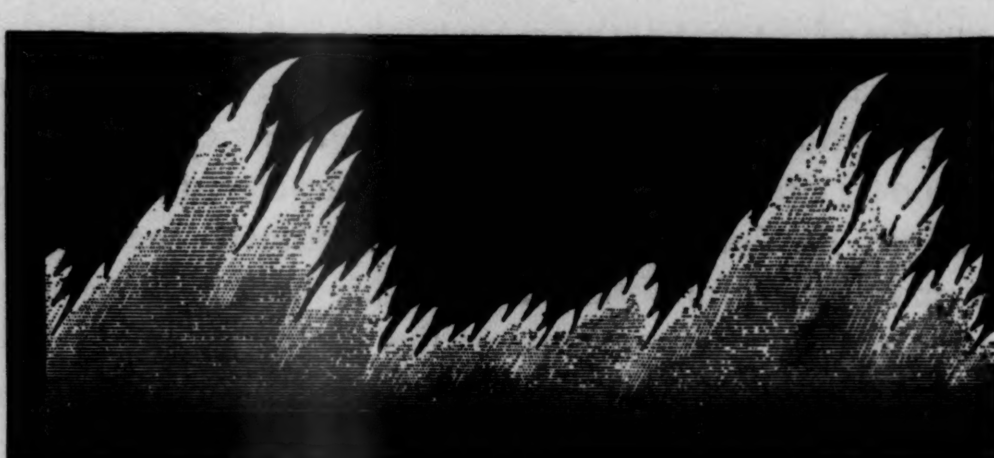


FIG. 17.

Such a wave is analogous to the synthetic wave made by combining the fundamental and a dozen or more series of partials of a vibrating string. The typical fluctuations in mental efficiency under these conditions might well be represented by the well-known composite curve from the manometric flame shown in Fig. 17.

2. *Second-waves.* — Such periods of mental activity as are grasped in uninterrupted waves of attention.

Attentive work runs in elementary periods the length of which depends upon the individual and conditions of work but does not ordinarily extend more than a few seconds.

The attention-wave of Urbantschitsch is typical of this periodicity whether the stimulus is strong or weak, constant or variable, objective or subjective.

[1] The word periodic is not used here in the mathematical sense of exact equality, but in the sense of approximate or relative equality of period. The factors which condition the fluctuations are so exceedingly complex and variable that there is no reason to expect such beautiful and exact symmetry as is shown in Fig's 16 and 17.

This wave is composite: it consists of relatively long waves of secondary passive attention and one or more relatively short waves of active attention.

Active attention appears only at the crucial points; the bulk of the second-wave is secondary passive attention. Active attention constitutes the determining moments and secondary passive attention bridges the gaps between these.

In a complete attention-wave, *i. e.*, a second-wave, there is one moment at which both active and secondary passive attention are at rest (not present). Unless the act consists of a single impulse, there are two or more moments of rest from active attention, but the secondary passive attention never has more than one.

The second-wave is irregular in outline, being the resultant of two components which vary with the individual and the conditions of the work.

3. *Minute-waves.* — Periods which contain more than one second-wave but are less than twenty minutes in average length.

Beyond the second-waves, attentive work runs in short composite waves; these combine in series as partials of longer waves and exhibit the phenomena of interference and reinforcement.

When the work is such that it may be perfect for considerable periods of time, as *e. g.*, the memory work after long practice, these waves do not show in the objective record, but introspection reveals their presence through fluctuations in ease, certainty, concentration, etc., and through awareness of mind-wandering, ennui, dullness, and other more or less certain accompaniments of change in capacity.

4. *Hour-waves.* — Periods lying between the minute-waves and the well-known diurnal waves in length.[1]

Beyond the minute-waves, attentive work runs in one or more series of long composite waves of efficiency. These are distinguished from the minute-waves because they are probably the result of different conditions from those which underlie the shorter waves.

[1] By diurnal waves, we mean such daily rhythms in efficiency as are due to routine work, eating, sleep, recreation, etc.

The hour-waves tend to get shorter as the work progresses.

There is no evidence of any constant tendency of observers to begin the work at the moment of greatest efficiency, or any other particular phase of the work curve.

5. *Correlation of Changes.* — Keenness of sensibility (*To*) and alertness (threshold width) are not closely correlated.

Keenness of sensibility (*To*) and variability (mean variation), are not closely correlated.

In these two cases it is not so much a question of degree of correlation as of type of tendency; some individuals give a high positive correlation and others give an equally high negative correlation.

Large variability (mean variation) and lack of alertness (threshold width) are highly correlated.

6. *Individual Types.* — There are evidences in these records to show that each individual probably has a fairly characteristic type of waves for similar work done under similar circumstances but at different times. This is true of all, from the short second-waves to the long hour-waves. This individual characteristic may show even in as radically different work as the three forms here employed.

7. *Consciousness of Change.*—The shorter the wave, the more clearly the observer is aware of the change. Introspection can always grasp the second-waves, but hour-waves may have large amplitude without the observer's suspicion of their existence.

The feeling of dullness does not correlate closely with poor work in waves of medium length. The very feeling of dullness comes from awareness of exertion. Low efficiency correlates better with periods of unconscious neglect, absentmindedness, mind-wandering, etc., which become known only as we catch ourselves in such shortcomings and forthwith make a new start.

8. *The Significance of Periodicity.* — The experiments were not planned so as to test any theory of the cause of all this periodicity, but it is reasonable to suppose that they are all evidence of nature's way of protecting the organism; the periods of dullness are periods of relative rest from which the observer

comes forth refreshed. It is common to speak of the failing of voluntary attention as nature's safety valve; the same figure may be extended to the whole series of periodicities.

Fatigue, practice, and adaptation errors have received critical examination in experimental method, but in these periodicities we have a factor which in many forms of experiment is as important as any of those named. In measurements for comparison which run over half an hour or more, what is only a part of wave may be taken for progressive change. This is especially so if the experiment is repeated in the same order and on the same observer who may have a definite type of periodicity.

This periodicity favors our normal working in short periods. When composing, *e. g.*, one writes during a moment of lucidity and then relaxes into a state of ennui and feeling of restriction, only to take up the period again. In free work such as that, the fluctuations are very much greater (and perhaps more efficient) than in work under experimental pressure.[1]

It has often been observed that, even in a situation of life and death, these periods of relaxation and absence of power set in, to our moral shock and great discomfiture.

These fluctuations are a part of nature's great scheme of rhythm. They are a condition of endurance and progressive mental development.

Their significance is analogous to that of sleep.

One may discover his most favorable rhythms and adapt his work to these. The art of effective work consists largely in selecting the most favorable rhythms, both long and various partials.

III. *Progressive Change.*

1. *General Tendency of Change in Efficiency.* — These experiments were not planned to isolate the factors which form a basis for progressive change. The aim was rather to secure faithful measurements of the actual efficiency from moment to

[1] Thus, the end tests in Series I. on the effect of a liminal sound upon the ear used and the ear not used in a two-hour period depend upon what phase of the long waves they are taken in. This is the chief reason why we could not draw any definite conclusion from those tests.

moment, regardless of the underlying shift of elements. Yet certain important progressive tendencies may be seen in the records.

2. *Practice.*—There is no noticeable gain from practice in simple perception and simple discrimination, after the observer has clear knowledge of the nature of the stimulus.

The improvement in a complex cognitive act, such as memory, is very great.

The improvement in memory work may be ascribed chiefly to progressive systematizing of parts in the act, the development of automatisms, the association of concrete imagery, and economical rest.

The practice is effective in impression, retention, reproduction, localization, and expression; but there is a tendency to make gain in one of these factors at a time. This leads to the step-like or plateau series of progressions.

The marked practice improvement ceases when the observer has reached the limit of his inventive power in systematizing.[1]

3. *Fatigue.*—Continuous liminal or moderately faint sounds do not seem to lower the efficiency of the ear in a two-hour test.

In the long period of the memory test, the faintest sound, which was clearly above the threshold at the beginning, became inaudible during the fifth hour of the work. There is nothing to show whether this is due to the long continuation of the work or to the stronger sounds in the group; nor was the test continued to determine whether this loss of sensibility was evidence of progressive or periodic change.

We failed to differentiate between the central and the peripheral fatigue by means of the 'before'- and 'after'-tests.

4. *Adaptation.* — Since the sensibility tests show no unmis-

[1] From the suggestion contained in these records, and from the accumulation of experimental evidences not published, we are inclined to believe that there is a general law which expresses the probability of gain by practice in any form of mental activity. This law is, *The practice gain is somewhat proportional to the complexity of the act.* In other words, where there is room for noticing new factors and simplifying, there is promise of practice gain. Simple perception and simple discrimination in the above records do not show any practice gain because the acts were simple, but the conditions of either could easily have been made so complex that there would have been a greater practice gain than in memory.

takable general rise or fall in efficiency and the discrimination tests show a fairly decisive decline; and since the strain of attention is about equal in the two tests and change in peripheral sensibility would have but little significance in the latter, it appears that there may be a general decline of central efficiency in both tests and that this is counteracted in some cases of the sensibility tests by an increase in the peripheral sensitiveness through adaptation.

5. *Types.* — The observers conform to different types with reference to progressive change. They may be divided first into those which show general gain and those which show general loss. Then each of these may be subdivided with reference to the rate of change and with reference to the time and cause of change.

A CASE OF VISION ACQUIRED IN ADULT LIFE.

BY JAMES BURT MINER, PH.D.

The opportunity of studying a case of complete congenital cataracts in which vision was not acquired until adult life is seldom given to a laboratory. About twenty cases of acquired vision have been reported in the psychological literature of Europe; in all except a few of these, sight was restored early in life.[1] So far as I can discover, there has been no psychological investigation of a congenital cataract case in this country. The present Iowa case, moreover, seems to be the first attempt to utilize the modern laboratory equipment for testing systematically and quantitatively the senses and the learning process of a blind person who has been made to see. The young woman here reported was blind from birth by reason of complete cataracts in both eyes. She was operated on when she was 22 years of age.

In order that there may be no misunderstanding, it should be stated that persons having complete cataracts can distinguish light and darkness. In the opinion of Dr. Ware, who reported two cases to the Royal Society of England, patients with cataracts 'are never so totally deprived of sight as to be unable to distinguish colors.'[2] In the famous Chesselden case the boy could distinguish scarlet previous to the operation.[3] These individuals are 'blind' in the popular and medical acceptation of the word; they make no use of their eyes in their daily work.

[1] W. Preyer, *The Mind of the Child*, 1889, Vol. II., appendix C., excerpts from cases of Chesselden, Ware, Home, Wardrop, and Franz; references also to cases of Hirschberg, von Hippel, and Dufour.

B. Bourdon, *La perception visuelle de l'espace*, Paris, 1902, Chap. XIII., refers at length to the above cases and also those of Albertotti, Uhthoff, and Vurpas and Eggli.

R. Latta, 'Notes on a Case of Successful Operation for Congenital Cataract in an Adult,' *British Jour. of Psych.*, 1904, I., 135-150.

The Medical Index Catalogue of the Surgeon General's Office, U. S. Army, Second Series, 1898, congenital cataracts.

[2] Preyer, *loc. cit.*, p. 293.

[3] Preyer, *loc. cit.*, p. 286.

It seems safe to say that no person absolutely blind from birth has ever acquired sight. If the nervous mechanism were intact, a blow on the eye would give the sensation of light. With cataracts, there seems to be no reason why a decided difference in the intensity of light cannot be distinguished; some notion of the distance of objects would be acquired by this means. If there is a distinction between light and darkness, when an object comes between a patient's eyes and the sun he should be able to get some sort of visual idea of diffused outline. Previous to the removal of the cataracts he might, therefore, associate a visual impression with an accompanying movement. This would give some degree of visual space perception. Franz's patient could distinguish a vertical from a horizontal line on the first trial after the operation. It seems as if this would always be possible. The patient's vision is in much the same condition as if he had always been compelled to look through a glass of milk. Not only is the transparency of the lens affected, but the refraction is also disturbed. Previous cases seem to have established the fact that after the removal of the lens the patient is not able to recognise objects with which he was perfectly familar by touch. Objects also appear larger than they did to touch; solids look like surfaces. In the points above mentioned the present case corroborates the conclusions of previous observers.

History of the Case.

In this paper I can only attempt a brief preliminary report of the case which came under observation recently at this laboratory. The young woman, Miss W., besides having unusual natural ability for her age, brought to her new visual experience all the training of an excellent high school course. She is a graduate of the State School for the Blind at Vinton, Iowa. Moreover, she is a splendid introspector, as blind people often are. Having been inclined for many years, by reason of her blindness, to watch her own mental states with considerable care, she has developed a remarkably keen power of observing and describing her psychical experiences. One incident will illustrate this. When her retinal color fields were to be mapped

with a campimeter, one of her eyes being covered, she was told to fix her other eye on a certain point and, holding the eye still, to tell what happened as a disk of color was drawn slowly away from the fixation point. Usually the observer will note, when the disk reaches a certain place (the limit of the field), that it disappears or changes into a different color. She, however, besides noting these facts, made the additional remark that 'just before the color leaves, it seems to grow much brighter; it almost glows.' This change in intensity is one which a skilled introspector often has difficulty in observing. Miss W. would rank well with introspectors of many years' training. Another circumstance made Miss W. particularly valuable for the series of experiments which we conducted. Her eyes had fully recovered from the operations and had been so strengthened by use that she could carry out extended tests without fatigue. She had been fitted with both far and near spectacles, so that she was able to find her way about, and could even read print with some facility.

The first successful operation on Miss W.'s eyes was performed at the School for the Blind in March, 1902, by the surgeon for the school, Dr. Lee Wallace Dean, who is also professor of ophthalmology in the medical college of the University of Iowa. The operation was that of needling, or discission of the lens of the right eye. A year later a successful discission of the lens of the left eye removed that also by absorption. As it was not until November, 1904, that we had the opportunity to study her case, she had already acquired much knowledge of the visual world. Since the first few days of sight have been so completely reported by observers of other cases, this delay was found not to be serious. Miss W. was still completely naïve to many of the normal visual experiences of an adult. She had never looked through a stereoscope, opera glass, field glass, or telescope. She had never used both eyes together enough to find out any differences between monocular and binocular vision. She had not yet learned to translate her visual images into terms of movement with any degree of success, except in case of the most simple forms and numbers or with common objects of her previous touch experience. She

knew practically nothing about drawings or pictures. She had not even learned to identify people by their faces; those whom she thought she knew by their features were her mother, father, sister, a teacher at the school, and the nurse who was with her during the operations. Although I worked with her every day for over a month and she saw Dr. Dean often, I believe she cannot yet recognize either of us by sight.

There seems to be no doubt as to the congenital character of Miss W.'s blindness. Dr. Dean states that the lenses were completely cataractous at the time they were removed. He says: 'I am confident that their extent had not changed from the condition at birth.' The young woman's father says that a peculiar twitching of the child's eyes was noticed soon after birth, but the family did not realize that she was blind until she was about four months old. The family physician states that, so far as he can remember, he diagnosed congenital cataracts at about that age. It should be stated that the reason why the eyes were not operated on earlier was that the parents had been wrongly advised by an occulist whom they consulted when she was a child.

Early in her life Miss W. seems to have amused herself by trying to follow the heavy black letters in a primer. Her practice in this respect at first seems to indicate that she may have seen slightly. A further consideration of the facts as she remembers them indicates that it was only playing at reading. As she relates the experience she says she could hold a large letter close to the corner of her eye and by moving the book she could tell when she left the black of the letter. Keeping the eye still and carrying the printed letter in different directions she determined what the letter was by the movements of her arms. It may be possible that this process was aided when she was young by light reaching the periphery of her retina between the iris and lens. It is curious that the left eye which she used in this practice shows a retina which has been atrophied for nearly a third of the distance from the periphery. In Miss W.'s case there was always the ability to distinguish white from black, and as near as we can determine by questions, she could also distinguish red, blue and yellow. These colors were, however,

so much duller that she hardly recognized them after the operation. She says that when she first saw her clothing it seemed to her as if she had 'an entirely new wardrobe,' the colors were so unexpectedly bright and different.

The general plan of the investigation was to first arrange a series of tests for touch, hearing, and sight by which measurements could be made of the lower, upper, and discrimination thresholds. The tests were to be standardized so that they might be used subsequently in any other laboratory in similar cases. They were also to be the basis for comparison with records from a group of normal individuals, to determine the effect of the disuse of the eyes not only upon vision, but on the other senses. Unfortunately, as yet there has not been time to prepare the group of normal records for comparison, so that the conclusions expressed in this paper must be largely tentative in nature. Another series of tests was planned to investigate her process of learning in the new field of vision. This touched a long list of problems of special interest to education, psychology and philosophy.

Tests of the Senses.

There is a popular idea that the loss of sight in a blind person is compensated for by greater keenness in the other senses. The present case offered a chance to determine how far this conclusion is supported by the facts. The tests on hearing show that Miss W.'s range of pitch is very wide. As tested by the Koenig bars and the Galton whistle, Miss W.'s upper limit is approximately 50,000 vibrations per second, and a rough test of her lower limit indicates that it is slightly below 16. Although she has this wide range of tone sensations, we found that her discrimination between simple tones was not unusually keen. With the tuning forks she distinguished, nine times out of ten, a difference of eight vibrations from the international a′ (435 vibrations). Tests with the audiometer also indicated that she was not far from the average in her discrimination and liminal thresholds for sound. Her localization ability was tested by Mr. Starch with the Seashore sound perimeter.[1] The most

[1] Daniel Starch, 'Perimetry of the Localization of Sound,' *Univ. of Iowa Studies in Psych.*, 1905, IV., 1.

noticeable factor here was an inordinate tendency to move her head in order to localize the sound.

With the sense of touch, the pith-ball test showed no peculiar sensitivity for passive touch. The æsthesiometer tests on the tip of the forefinger were not numerous enough to be accurately stated, but they indicated that two points could be distinguished when 1½ mm. apart. Active touch was tested by a more satisfactory method. A piece of very fine steel wire (No. 35 B. & S.), 7 cm. long, was laid on a plate of glass. It was then covered with 43 sheets of letter paper (Brother Jonathan Bond, 17 × 22, 20 lbs. to the ream, 500 count). Miss W. determined correctly ten times in succession whether the wire was in a vertical or horizontal position. With 44 sheets she was right eight times out of ten. It is impossible as yet to give normal records for comparison.

So far as these tests on hearing and touch go, it seems to me that they give good evidence that training has improved her active touch and probably increased her interest in overtones to such an extent as to somewhat enlarge the range of pitch. She recognizes people entirely by their voices. For this purpose the noticing of overtones is more important than fine discrimination of simple tones. I would conclude, therefore, that the effects of training in active touch and hearing are evident, but there is little evidence that the native untrained capacity of other senses than sight has been increased. We may suppose that persons who have always seen could, by similar training from birth, make equally good records in hearing and touch.

In the examination of Miss W.'s vision, it was found that, without spectacles, she could read letters on the Snellen charts at 20 cm. distance which normally are read at 500 cm. Considering the fact that she has no lenses in her eyes, this may be regarded excellent. Dr. Dean has provided her with distance glasses having a spherical correction of + 10 diopters. According to his record her vision with these spectacles is 6/36; this means that she reads at a distance of six meters what she ought to read with normal eyes at a distance of 36 meters. Her reading glasses have lenses of + 13 diopters. With these

I found that she could read much smaller than the usual newspaper type (Snellen's D. 1.2) when she held it close to her eye. The campimeter and ophthalmoscope show that about one third of the outer part of the left retina is useless. Otherwise the relations of the visual area and color fields seem normal. Aside from the lack of lenses, Miss W.'s vision is also affected by the constant twitching of her eyes (nystagmus) and by cross-eyedness (concomitant convergent strabismus). These often accompany congenital blindness. There is some indication that the strabismus may be partially overcome, as will be explained in the discussion of binocular vision. Tested with prisms, the horizontal convergence cannot be corrected by a twenty-degree prism. A prism of from 4 to 6 degrees is necessary to correct the vertical disturbance.

The color vision of Miss W., it may be safely said, is decidedly above the average. She can detect color in solutions that are perfectly transparent to those of us who have been working with her in the laboratory. She can also discriminate differences in tint which are considerably below our threshold. In looking at the spectrum, she can apparently see ultra-violet which is beyond the usual field of view. The interpretation of her observations of the spectrum is a matter of some perplexity, so that I would not be sure of the present record without further check experiments. Preliminary work with the spectroscope indicates that her spectrum is about one fifth longer than the average of ten students. The length is added to the violet end. I suspect that this difference is largely due to a difference of interest in the test. In the examination of the color threshold and discrimination, the Lovibond tintometer was arranged for standard daylight, which was regulated and measured photometrically each day. With the intensity of light which was used, she was able to discriminate 16 times out of 20 a difference in red amounting, in the units of the instrument, to 1 in 700. Tested also for the threshold of color, she was able to name correctly red, green, blue and yellow nine times out of ten when the slides .2 were used. In the slides supplied with the instrument, .1 is the only lighter tint that is furnished. Two students who were tested became insensitive to color at slides .5 and 1.0;

they failed to discriminate reds, under the same conditions as Miss W. worked, when the difference in shade was 1 to 20. Another series of tests was started to check these results, using standard solutions of blue and red instead of the Lovibond tinted glass slides. As yet I have no records for comparison. The reaction time for discriminating white, black, red, green, blue, yellow and orange has been obtained. The examination of Miss W.'s perception of color contrast and after-images shows that in these respects she is practically like other individuals.

These facts of color vision seem to me to have some importance for biology. Twenty-two years of almost complete disuse of the retinas have caused no degeneration of the color process so far as can be determined. The tests point rather to a color vision beyond that of the normal adult. This seems somewhat contrary to what might be expected. The fact may be explained in several ways. It is possible that further tests on other adults may show normal individuals who can reach Miss W.'s record in color discrimination. Should equal records be made by any other adult, I should be inclined to believe that the pronounced difference manifested between Miss W.'s color vision and that of us in the laboratory is a difference due to her decidedly greater fascination for color. On the other hand, if the normal adult cannot equal her record, we seem to have a suggestion that the color process of the retina may degenerate with use. On account of the difficulty of interesting children in the tests, negative records made on those who are younger would hardly determine this point. The fact that there are no lenses in Miss W.'s eyes is also to be borne in mind; this may give her a clearer vision of color. So far as the evidence at present stands we seem to have several possible conclusions. The lens may obstruct our view of color, the color process may deteriorate with age, or a phenomenal interest in color may increase our liminal and differential sensitivity for light far above the average.

Apart from her remarkable sensibility to color, one of the most surprising facts thus far discovered is that Miss W. sees black objects larger than white objects of the same size. This reverses the usual illusion of irradiation. Measurement of the illusion shows that a white isosceles triangle with a base of 5 cm.

and altitude of 8 cm. appears to Miss W. as equal to a black triangle of 7 cm. altitude. The average variation from the altitude 7 is only .2 cm. for 16 trials. Using a special form of the method of right and wrong cases, a white square of approximately 5.5 cm. was selected as equal to a black square 5 cm. on a side. One of the most interesting features of this anomaly occurs with the illusions which are thought to depend on irradiation, the Münsterberg figure of the shifted checkerboard and the kindegarten pattern which is related to it.[1] Miss W. says that she is able in both these illusions to perceive the lines tilted in either direction with about equal facility, although at first she saw the checkerboard illusion reversed.

It is difficult to say what may be the explanation of this curious contraction of the white field or expansion of the black. I have suggested that it seems to indicate that the illusion here depends more on a brain process than on a retinal process, that it is connected with our general interest in bright things and disregard of dark objects. In Miss W.'s case the reversal of the white and black square illusion would be explained by the fact that during her twenty-two years of blindness it was really black objects which were the most important in her experience. When something dark came between her and the light, it was an obstacle to be avoided. The normal child, on the contrary, always actively demands what is bright and is continually interested in the more intense colors. It might be well to measure the illusion in persons suffering from melancholia, among whom darker colors are said to be more appreciated. The hypothesis that the central process is most important in Miss W.'s experience of this illusion is corroborated by the fact that she is able to reverse the kindergarten pattern. I believe that the irradiation illusions will acquire their usual form with her after more experience; I even found some indications of this during her stay at the university. The facts seem to establish that the peripheral diffusion of the light stimulus, if it occurs, is easily outweighed by the central condition. It is possible that irradiation is always central rather than retinal.

Aside from irradiation, Miss W. seems to obtain the common

[1] A. H. Pierce, *Studies in Space Perception*, New York, 1901, p. 213.

visual illusions normally, unless it be the illusions of interrupted space and those dependent upon perspective. In these latter cases her introspections at different times are in conflict. The Müller-Lyer and the cross illusions were measured for comparison between Miss W. and other individuals. I found no reason to suspect that the results with the Zöllner and Poggendorf figures were any different for Miss W. than for others. Records of the reproduction of horizontal lines by sight and by touch were obtained for comparison. They afford some evidence as to the relative value of visual and tactual space.

Investigation of the Learning Process.

Besides testing Miss W.'s senses of vision, hearing, and touch, the main effort has been to study the process by which she learns to interpret what she sees. Undoubtedly the most fascinating work along this line was in connection with the development of binocular vision. It is a prevalent belief among physicians that the ability to see objects single when using both eyes must be acquired early in life or not at all. It has been suggested that the necessary association paths in the brain cannot be developed in adult life. The occulists point to many cases where a condition of crossed eyes has been corrected in adults, by operations on the eye muscles, and yet single binocular vision has not been attained.[1] In such cases the individual neglects the image of one eye. Miss W. was in much the same condition as any cross-eyed person, except that she had used her eyes for only two years. Some idea of the progress which was made in the few weeks during which she was at the laboratory may be gathered from the following incidents.

While she was still naïve on this subject, I asked her to look through two small tubes, one held before each eye in such a manner that, if she desired, she could look with both eyes at the same object without moving the tubes. Under these conditions and looking at a single cone standing on the table, she said: 'I see two cones, one with the right eye and the other with the left.' She was quite emphatic about seeing two cones

[1] The question is in dispute, Landolt gives instances in which he trained patients, who were formerly cross-eyed, to get single binocular vision. Norris and Oliver, *System of Diseases of the Eye*, Philadelphia, 1900, IV., 151.

on the table. This was undoubtedly the usual way in which she interpreted the images from her two retinas.

The same effect was obtained in even a more striking way when Miss W. was provided with spectacles having differently colored glasses. Asked to describe how a large white surface appeared through the spectacles, she said: "Why, I see a large sheet of red cardboard with my right eye and a sheet of green cardboard with my left eye. They are both in the same place and I am just as sure that I see them both at the same time as I am that I am standing here." When carefully questioned if one card was not seen after the other or behind the other, or if one part of the surface was not red and the rest green, she persisted in her first statement. She said that she could not understand how there could be two different surfaces in the same place at once but that was the way she saw them. Under the most careful experiments with gelatines of unknown color before her eyes and instantaneous exposures by an electric spark (conditions under which others in the laboratory were able to see but one color, on account of the tendency to retinal rivalry), Miss W. still maintained her perception of two surfaces of full size and of different colors, not overlying each other in any way.

If the psychologist should say that probably Miss W. did see two surfaces in the same place at the same time, we might be somewhat confounded by the mathematical axiom. However, it seems to me that we are forced to admit that she really did see two things in the same place at the same time. Furthermore, I am inclined to think that this may be the usual impression in childhood under like conditions. Moreover, there may be two moons for the child. Our later interpretation of what we see is a matter of education. We learn, of course, that there are not two objects, so we neglect the doubling of our eyes; or we disregard the image of one eye thus developing our phenomenon of retinal rivalry. It is possible that this rivalry of retinal images arises somewhat late in the child's life, and is only gained after the visual experience is tested by touch. From a subjective point of view, we may be quite confident that, for Miss W. at least, two differently colored surfaces were seen in the same place at the same time, and, also, that she naïvely believed that she saw two cones when there was only one.

Under these circumstances the experiences of Miss W. with the ordinary stereoscope were exceedingly interesting and suggestive. As soon as it was discovered that she had never looked through a stereoscope, every precaution was taken to leave her completely naïve as to the effect of the instrument. The series of stereoscopic views used by occulists and the imported Martius-Matzdorff set were employed in the experiments. After some practice, it became apparent that there were hints of single binocular vision. At times she would say that she saw one figure, instead of stating that she saw one figure with her right eye and another with her left. The latter interpretation, however, continued when there was any marked difference between the two parts of the stereoscopic view. In a few cases I believe that I succeeded in getting her to combine views in which the picture before each eye had other differences than those necessary for giving relief. She thought also that she finally succeeded in seeing the sheen which results from combining black and white.

Before the experiments stopped, she had so far progressed with single binocular vision that she had no difficulty in seeing the ordinary stereoscopic picture in full relief, and she readily picked out views with no relief, and with a pseudoscopic effect. The usual precautions were taken to make sure that she was not merely saying that she saw single with both eyes, if she was unconsciously neglecting the image of one eye. As checks against this possibility, the partition between the prisms was removed, and she noted the three pictures visible; one side of the slide was covered, and she noted the shifting of the picture from the center to the side. Finally, accurate tests were made upon her ability to discriminate distances with both eyes compared with her monocular ability. Different sized balls were hung at varying distances from her. Using only one eye she judged them to be at the same distance when one was 15 cm. farther away. But the difference between the two balls was narrowed down to 6 cm. when both eyes were converged on one ball and then on the other. Her error was thus cut in half by using both eyes together. On account of her long standing strabismus hese tests were extremely fatiguing. At best she was able to

keep her eyes converged only a few minutes at a time. The improvement was so marked in the short time she was being trained, however, that her ambition to overcome her cross-eyedness does not seem entirely hopeless.

The introduction of Miss W. to a clearly outlined view of nature in perspective, which she first had in looking through the opera glass, afforded another series of introspections which mean much for the theory of space. The limits of the present article do not permit publishing the dialogues between Miss W. and the experimenter over this experience as it developed. They covered inquiries as to how she knew the picture was real, the interpretation of objects seen in unnatural size with the glass reversed, etc. Her æsthetic preference for blurred over clear outlines in certain circumstances is an interesting contribution to the defense of impressionistic art. These experiments were followed by an attempt to find out how she learned what perspective in pictures meant. Beginning with simple line drawings, she was gradually led to the interpretation of complex scenes and even cartoons. The latter still distress her very much. 'Why do they make all the people look so ugly?' and 'What are all those lines on their faces?' were some of her comments about newspaper drawings. Considerable material has been gathered which may give helpful hints for teaching drawing. The child every day lives through modified forms of the experiences which Miss W. had in the laboratory.

From the psychological point of view, it was important to determine whether the development of her conceptions of form, solidity, distance, and number always required the translation of visual images into movement and touch terms. Her all-powerful impulse to explain anything new by referring it at once to the language of her sightless experience, makes the interpretation of her visual consciousness very difficult. By showing some novel figure to Miss W. for a few hundredths of a second through an exposure shutter, it was possible to study how she perceived, imaged, and interpreted it. After repeating the exposure many times, her method of counting the sides of a figure could be observed. With practice she was able to obtain an indistinct image and then count the sides after the picture had been withdrawn, although she could not count the sides

during the time of the exposure. Kinæsthetic sensations undoubtedly play a most important part in her conceptions of number and space. When Miss W. was directed to count the sides of a hexagon, but to shut her eyes the instant she caught herself making any movement, and then begin again, I found that she was not sure of the number of sides after observing the figure a total of five minutes. She would not look at it continuously more than 10 to 20 seconds without beginning to count its sides by using some muscular contraction to mark each corner as she changed her attention from one part of the visual impression to another. She would tap with her fingers or foot, press her teeth together or her tongue against her teeth, move her head, regulate her breathing, or even slightly wink at each corner, in order to register that as number one before passing to the next. On account of this irresistible impulse to move and to touch, it may be doubted whether a blind person who acquires vision is a suitable subject to decide whether visual images have spatial meaning apart from movement. In no case, I believe, has Miss W. ever questioned the extension characteristic of her visual sensations. So far as the experiments went, they corroborated the current hypothesis that shape and number get their meaning from touch and movement.

Many instances might be cited to show the difficulty Miss W. has in interpreting her visual experience. For a long time, shadows were quite troublesome to her. They seemed like real objects. Once in a while she still catches herself walking around a shadow on the sidewalk, or stepping over it as she would any obstacle in her path. Dishes were upset at the table because she could not judge their position. A cat a short distance away was mistaken for a chicken. The color of an old waist appeared so different that she could not recognize the garment for some time after touching it. Except for the color, she would probably have known it at once. She finally made sure by feeling the pin holes in the cuffs and by looking at it with the eye which had not been operated on. The morning after she looked through the university telescope at the stars, she anxiously inquired: 'Could you see any points on the stars?' Her previous touch experience had associated star with a pointed figure. Although her numerous natural blunders in trying to

understand her new experience are exceedingly interesting, they do not seem nearly so remarkable as the marvelous ability she constantly manifested to interpret novel experiences which she knew nothing about previously or knew only by description. The compass, for example, was recognized by sight at once from what she had learned about the magnetic needle, although she had never seen one. All sorts of strangely shaped blocks, complicated pieces of machinery, scenes in the field glass, etc., were accurately described without touch. The fact that so much could be done with the little practice that she had had suggests that too much emphasis ought not to be given to a current theory concerning the non-spread of training. If training is a greatly specialized process, we should expect in Miss W.'s case that the ability to memorize by touch and sound would be markedly better than by sight. When I suggested testing her visual memory, she said at once that she could not remember what she read in print. The preliminary tests which I have been able to carry out, however, indicate that there are only slight differences between auditory, touch and visual memory of a series of letters or of sentences. It is true, no doubt, that the thought to be remembered in all these cases is translated at once into movements of the vocal organs. She repeats to herself what she is reading or hearing. But the fact that visual sensations can be associated so accurately and permanently with the vocal movements of the larynx is still important evidence of the spread of memory training. Unfortunately the tests have not been carried far enough to be conclusive. I can give little more than a general impression. Her reproduction of passages from 'The Greatest Thing in the World,' read by point type, by sound, and by sight was recorded, as was also her memory of twenty letters irregularly arranged and read in the three different ways for several days in succession — until she had committed them all. No weakness of visual memory, or of the translation of visual terms into muscular, if that is the way we remember, was apparent in either of these tests. Further experiments on Miss W. along this line seem to offer a most promising field for educational investigation.

Before the more complete technical description of the experiments and the quantitative results are published, it is desira-

ble that the tests should be repeated on a representative group of normal adults. The conclusions here given are necessarily very guarded because they must depend to a large extent upon impressions gathered from a general survey without adequate opportunity for comparison. In a paper of this length I can only hope to hint at the bearing which the facts discovered have upon various psychological theories. New problems opened up almost daily. The case promises quite as valuable results along other topics of eductional, biological and philosophical importance as those taken up. In the field of psychological æsthetics, naïve preferences were expressed which have interest in connection with primitive conceptions of visual beauty. In the genetic aspect of the case, more work might well be done.[1]

Briefly summarized, the suggestions from a review of this case are: (1) While hearing and touch show great keenness in some respects, there seem to be no records which cannot be explained on the basis of greater interest and training, and without supposing a compensatory change in the capacity of these sense organs. (2) Color vision is so far above normal as to contradict any supposition that 22 years of disuse would cause degeneracy. On the contrary, either the color process deteriorates with use or the removal of the lens and unusual interest produce a remarkable ability to discriminate colors. (3) The reversal of irradiation indicates that a central process may readily outweigh the retinal process. (4) The absence of retinal rivalry suggests that this process is developed by education; and the tendency to regard a single object as double indicates that this is the nature of the first visual experience with two eyes. (5) Contrary to a prevalent opinion, single binocular vision may be acquired, at least temporarily, by an adult born blind. (6) Number and space perceptions are apparently dependent upon movement. (7) An unexpected spread of training, especially in memorizing the visual impressions of printed letters and sentences, suggests a caution as to the amount of training which an intelligent adult may transfer from one field to another.

[1] I desire to express my thanks to Prof. Carl E. Seashore, Mr. Daniel Starch, and Mr. E. A. Jenner. Their suggestions and assistance made it possible to carry out many experiments which could not otherwise have been performed. To Dr. L. W. Dean, also, for his hearty coöperation in the present study.